VDA

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. LXXIV.

EDITED BY

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ERRATA.

Vol. lxxiii., p. 309, Note 6, *for* 42° 34′ 34″, *read* 42° 30′ 34″ as the mean value of angle A.

„ „ „ „ n = number of observations of each angle.

„ „ „ „ *Insert* 4·5 as the denominator in the second member of each of the three numerical equations.

„ „ „ „ *for* (30′ 34″ ∾ 30′ 45″), in the second member of the first numerical equation, *read* (30′ 34″ ∾ 30′ 45″)².

„ „ p. 310, Note 7, *for* (x', $x'' - x'''$, &c.), *read* (x', x'', x''', &c.)

Vol. lxxiv., p. 39, lines 25 and 26, *for* "the inertia motion of which," *read* "with which the inertia of motion."

„ „ p. 68, line 6, *for* "£5,000," *read* "£10,000."

THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1882-83.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS.

24 April, 1883.

JAMES BRUNLEES, F.R.S.E., President,
in the Chair.

(*Paper No. 1830.*)

"Resistance on Railway Curves as an Element of Danger."

By JOHN MACKENZIE, Assoc. M. Inst. C.E.

THE friction caused by the unequal and indirect action of the wheels of a locomotive engine or carriage on curved rails is a source of additional tractional resistance,[1] and also of a considerable amount of danger,[2] from the tendency of the wheels to run off the rails; and it is entirely with regard to this danger that the subject is treated in this Paper.[3]

On looking over the Board of Trade Returns of Railway Accidents for several years, it will be found, in most of the cases in which engines left the rails without a tolerably obvious cause, that the engines were six-wheeled with parallel axles, and in some cases were running at low speeds; indeed in one case the speed was so low that the centrifugal force was more than balanced by the cant of the rails, so that some other agency than centrifugal force was evidently at work.

The tendency which a wheel has to mount the rail on a curve is evidently caused by the adhesion or friction between the rail and the flange of the wheel, and this adhesion will bear some proportion to the side pressure with which the flange is forced against the rail. In the case of the wheel most likely to mount the rail, namely the outer leading wheel, this side pressure, at low speeds,

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[1] Minutes of Proceedings Inst. C.E., vols. xviii., p. 51; xxiii., p. 406; xxvi., p. 310; xxxi., p. 358; lxiii., p. 388. Transactions of the American Society of Civil Engineers, vol. vii., p. 78.

[2] "The Builder," vol. xxxv., p. 334.

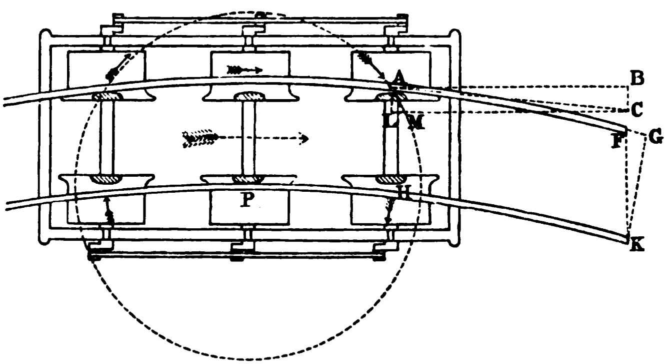
[3] Appendix I.

is principally caused by the resistance which the treads of the wheels oppose to the sliding motion which takes place in running round a curve.

Taking the case of an engine with six cylindrical wheels[1] on three parallel axles, all coupled, the middle or driving axle being midway between the other two:—when such an engine is running on a curve, and the clearance is the least possible, so that the flanges of the wheels just fill the space between the rails, then the driving axle is radial, the wheels on the leading axle tend to run outwards, and those on the trailing axle to run inwards. Fig. 1 represents such an engine or carriage as seen from below, showing in section the parts of the flanges which project under the level of the top of the rails.

The flange of the outer leading wheel is pressed hard against the rail. The flange of the inner driving wheel is parallel to the rail, and has of itself no tendency to press against it, but is kept close

Fig. 1.



to it by the trailing wheels: the outer trailing wheel, although the flange is kept close to the rail by the outer leading and inner driving wheels, has a tendency to leave the rail; and the inner trailing wheel, notwithstanding the tendency to run against the rail, has the flange kept clear of it by the outer leading and inner driving wheels.

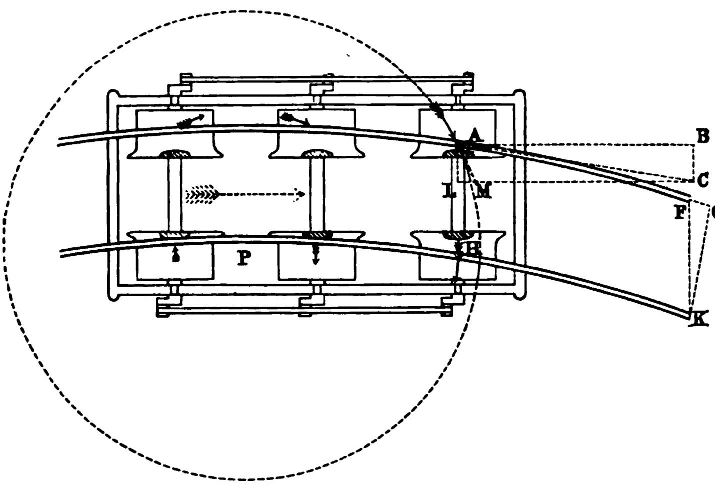
If now the flange were removed from the outer leading wheel, the engine would run straight forwards, and (if the flanges of the other wheels allowed it to run so far) this wheel, in making one revolution, would run from A to B; but it is compelled by the flange to move in the direction of the line A C, a tangent to the curve at A, so that it slides sideways through a distance equal to B C.

[1] Appendix II.

If this wheel were loose on the axle, it would, in making a revolution, run along the rail to F; but the inner wheel, in making a revolution, would run forwards from H to K, the centre line of the axle being K G; so that, if both wheels are keyed on the axle, either the outer wheel must slide forwards or the inner wheel backwards. Assuming that the engine is exerting no tractive force, and that both wheels revolve at the speed due to the inner wheel,[1] then the outer wheel will slide forwards from F to G. Take A L equal to B C, and L M equal to F G, the diagonal A M is the distance which the outer wheel slides in making one revolution.

In the same way may be found the distance which each of the other wheels slides, as indicated by the short black arrows, all of

Fig. 2.



them moving approximately in circles about the point P, where the inner driving wheel touches the rail, so that the sliding of the wheels is similar to that which would take place if the engine, without moving forwards, were made to revolve about the point P.

When the coning of the wheels exactly suits the curve, the leading wheels, and in this case the trailing wheels, do not slide along but only across the rails; but the sliding of the driving wheels is increased if the wheels are coned, unless indeed they are coned in the opposite direction to the others.

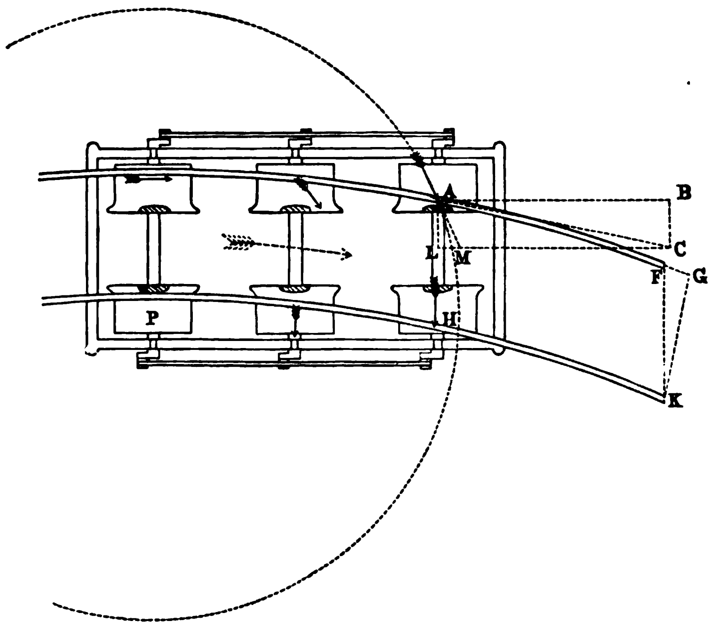
When the clearance between the rails and the flanges of the wheels is increased to just a sufficient extent to allow the inner

[1] Appendices II. and III.

trailing-wheel flange to run against the rail (Fig. 2), then the driving axle is not radial, but has the inner end slightly in advance of a radial line, and the trailing axle has the inner end slightly behind a radial line, and the sliding motions of the wheels take place round a point P, situated between the driving and the trailing wheels. In this case the sliding of the trailing, as well as of the driving, wheels is increased if the treads of the wheels are conical.

When the clearance is increased, or the radius of the curve increased, to a still further extent sufficient to allow the inner trailing wheel to run with the flange just clear of the rail (Fig. 3),

FIG. 3.



then the position which the engine takes up on the rails depends somewhat upon the comparative loads on the wheels. The driving wheels, in following the leading wheels, have a tendency to assume a position with their axis radial;[1] but the trailing wheels have the same tendency, and it is impossible that both axles can be radial. If one pair of wheels is much more heavily loaded than the other, the more heavily loaded pair will run with the axis radial; but the tendency of the trailing wheels to run forwards is increased by the tendency of all the inner wheels to outrun the

[1] Appendix II.

outer ones,[1] so probably the trailing axle is generally radial, and the sliding motions of the wheels take place round a point P, situated where the inner wheel touches the rail.

In order to cause these sliding motions, the outer leading-wheel flange exerts against the rail a pressure sufficient to overcome the adhesion or friction of the treads of the wheels; this pressure being exerted directly on the leading wheels, and transmitted to the other wheels through the medium of the engine-framing acting as a lever with its fulcrum at P.

The resistance which a wheel opposes to sliding across the rail probably does not differ much from its adhesion for traction; and the pressure exerted by the leading-wheel flange to overcome this resistance or adhesion will, for each wheel, be approximately equal to the adhesion of that wheel multiplied by its distance from the wheel which acts as fulcrum, and divided by the distance of the leading axle from the axle on which is the wheel acting as fulcrum. These pressures being taken for each wheel, the sum of them will be the total side pressure on the outer leading-wheel flange.

When the flange of the outer leading wheel is on the point of mounting the rail, the tread, being relieved of pressure and adhesion, need not be taken into account in estimating the pressure on the flange.

The distances which the several wheels slide vary with the sharpness of the curve, but the adhesion remains constant; so that although the energy expended in causing the wheels to slide while the engine runs a certain distance along the rails increases with the sharpness of the curve, the pressure in the line of the axle required to effect this sliding is nearly constant, whatever may be the radius of the curve. The pressure exerted by the flange on the rail is, however, slightly greater than that in the line of the axle, as that line is not at right angles to the rails, and this pressure increases as the secant of the angle at which the wheel stands on the rails. As this angle can never in practice exceed 2° 30′, and the secant of 2° 30′ does not exceed the radius by one-thousandth part of its length, the additional pressure arising from increasing sharpness of curve may be neglected.

On a curve, the point of contact between the outer leading-wheel flange and the rail is in advance of a perpendicular from the wheel's axis, so that the motion of the wheel at that point is downward, imparting a downward pressure to the rail, and an upward pressure to the wheel. Thus, when the adhesion between the flange and

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[1] Appendix II.

the rail is greater than the weight upon the wheel, the flange would rise and mount the rail even if the surfaces at the point of contact were vertical; and when they are inclined (as they always are), the tendency of the wheel to rise is augmented.

Owing to the downward motion of the flange at the point of contact, the side pressure required to cause the flange to mount the rail is, not the pressure which, when the wheel is at rest, would force it over the rail in opposition to friction as well as to gravity, but the very much smaller pressure which, when the wheel is at rest and the tread slightly raised above the rail, would cause friction sufficient to prevent its falling into its place again.

With a wheel and rail whose surfaces at the point of contact do not appreciably vary from the vertical, the wheel would be caused to mount the rail by a side pressure bearing the same proportion to the load on the wheel which the load bears to the adhesion.

When the surfaces at the point of contact are inclined (as they always are), the pressure required to cause the wheel to mount the rail diminishes rapidly as the angle of inclination increases; as, with an angle flatter than that down which the one surface would just slide on the other, the flange, if raised, would not slide back into its place even if there were no side pressure.

When the outer leading wheel begins to rise, the increasing deflection of the spring opposes a greater resistance to its rising further. This tendency to rise, while the conical part of the flange touches the rail, is nearly constant so long as the proportion of adhesion to pressure is constant; but if this proportion raises the wheel to such an extent that the rounded edge of the flange begins to come into contact with the rounded corner of the rail, the tendency to rise increases more rapidly than the resistance of the spring, and the wheel, which has then passed its maximum of stability, mounts the rail.

The higher tension of the spring adds to the load on the outer leading wheel, and at the same time raises the centre of gravity of the engine, and alters the distribution of the remaining weight on the other wheels, this redistribution varying with different arrangements and proportions of springs.

It has not been proved experimentally whether the friction of the flange against the rounded corner of the rail is the same, in proportion to the pressure, as is that of the tread against the crown of the rail.[1] The surface of a cylindrical tread may run on a straight rail without any sliding motion whatever; but the highly inclined

[1] Appendix IV.

surface of the flange can never run against the rounded corner of the rail without some portion of even the very small surfaces in contact sliding. It is therefore possible that the flange-friction partakes of the nature of the friction of a skidded wheel, or of a wheel against a brake-block which has been found to diminish at high velocities;[1] and this possibility is almost rendered a probability by the circumstance that, of the cases reported of engines leaving the rails, comparatively few occurred at high speeds. This is the most doubtful part of the question; or rather it is the only really doubtful point: the rest is a mere mechanical problem, but an extremely complicated one.

In the absence of information on this point, it will be assumed that, at moderate velocities, the flange-friction bears the same proportion to the pressure as does the adhesion of the tread, and that the two vary together when the state of the rails varies. This being so, with a doubled coefficient of friction the side pressure on the leading-wheel flange, required to make the other wheels slide, is doubled: at the same time the proportion which the flange's own adhesion bears to that side pressure is also doubled, so that the adhesion of the flange is fourfold. In other words, the tendency to mount the rail increases as the square of the fraction representing the coefficient of adhesion; or rather it would increase in this ratio if the surfaces were vertical, but when they are inclined the ratio is less rapid.

When the leading flange is lubricated, its friction is nearly constant, so that the tendency to rise increases only in the simple ratio of the adhesion, instead of in the duplicate ratio.

It is evident that, if there were no friction between the rails and the treads and flanges of the wheels, the outer leading wheel, when running slowly on a curve, would have no tendency to mount the rail; and equally evident that if the friction were infinitely, or very, great, the engine would run straight forward over the rails. Between these extremes there must be a certain proportion of friction which will just balance the weight on the wheel, and any addition to this friction would cause the wheel to rise over the rail. This differs in different engines; and if for any engine the proportion of friction which will cause it to leave the line is one that may occur in certain conditions of the rails, then that engine is dangerous in the extreme; and any engine is so to some extent, which has not, in this as in other respects, a considerable margin of safety.

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[1] Institution of Mechanical Engineers. Proceedings. 1878, p. 172.

Captain Douglas Galton, C.B., Assoc. Inst. C.E., in giving the results of his experiments on the adhesion between wheels and rails, states that "On dry rails it was found that the coefficient of adhesion of the wheels was generally over 0·20. In some cases it rose to 0·25 or even higher. On wet or greasy rails, without sand, it fell as low as 0·15 in one experiment, but averaged about 0·18. With the use of sand on wet rails it was above 0·20 at all times; and when the sand was applied at the moment of starting, so that the wind of the rotating wheels did not tend to blow it away, it rose up to 0·35, and even above 0·40."[1]

Thus an engine could not be considered safe if, when the adhesion rose to 40 per cent. of the weight, the side pressure on the flange of the leading wheel were sufficient to prevent the flange, when raised, from sliding down again on the side of the rail.

To apply the foregoing to the case of an engine which actually left the rails, the following example may be taken from the Board of Trade Returns as to railway accidents,[2] where the circumstances are thus reported:—"The branch leaves the main line on a curve to the right, with a radius of only 640 feet. . . . There is a cant of 2¼ inches. The engine is a four-wheel-coupled tender-engine, with a wheel-base of 14 feet 4 inches. The weights on the three pairs of wheels are—

	Tons.	cwt.
"On leading wheels	7	8
,, driving ,,	10	13
,, trailing ,,	7	12
Total	25	13

"The engine itself is in good order, and there is no reason to attribute the accident to any fault in the rolling stock. The speed was, no doubt, as much as 15 miles an hour, the authorized speed, but . . . there is no reason for supposing that this speed was exceeded.

"The road did not gauge very evenly from the facing points southward, being in some places as much as $\frac{9}{16}$ inch slack, and in others exact to gauge."

The Inspector goes on to say: "I am of opinion that this accident was due to the want of a proper check-rail at this curve of under 10 chains radius, and to the somewhat slack state of the permanent way."

Assuming that each wheel had an independent spring which (not to overestimate the danger) may be assumed to have been stiff enough to deflect only 2 inches with its usual load; and that

[1] Institution of Mechanical Engineers. Proceedings. 1879, p. 174.

[2] Railway Accidents, Returns, &c., April 21, 1879.

the driving axle, with its wheels, weighed $1\frac{1}{2}$ ton, and the leading and trailing axles, with their wheels, 1 ton each; and that the outer leading wheel rose $\frac{1}{2}$ inch before the rounded edge of the flange came into contact with the rail,—then this additional deflection of its spring probably increased the load on this wheel to about 4 tons 1 cwt., and caused the remaining weight to be distributed on the other wheels somewhat as follows, namely:—

	Tons.	cwt.
On the inner leading wheel	3	10
" outer driving "	5	0
" inner " "	5	7
" outer trailing "	3	15
" inner " "	4	0

Assuming that the inner driving-wheel flange was pressed against the rail, and also, as a preliminary, that the adhesion was $\frac{1}{5}$ of the weight, the pressure exerted by the outer leading-wheel flange in causing the treads of the other wheels to slide on the rails (its own tread being lifted clear of the rail), was probably—

		Ton.
For the outer leading wheel	$=0\cdot0\,(4\cdot05\times7\cdot16=29=N)$	$=0\cdot0000$
" inner " "	$=0\cdot2\,(3\cdot5\times7\cdot16=25\cdot060)\div7\cdot16$	$=0\cdot7000$
" outer driving "	$=0\cdot2\,(5\cdot0\times4\cdot916=24\cdot580)\div7\cdot16$	$=0\cdot6866$
" inner " "	$=0\cdot2\,(5\cdot35\times0\cdot00=0\cdot000)\div7\cdot16$	$=0\cdot0000$
" outer trailing "	$=0\cdot2\,(3\cdot75\times8\cdot61=32\cdot287)\div7\cdot16$	$=0\cdot9018$
" inner " "	$=0\cdot2\,(4\cdot00\times7\cdot16=28\cdot640)\div7\cdot16$	$=0\cdot8000$

$$M = 110\cdot567 \text{ foot-tons.}$$
$$15\cdot44 = 110\cdot567 \div 7\cdot16$$
$$0\cdot2\times15\cdot44 = \quad \text{tons } 3\cdot0884$$

or say a little over 3 tons.

Next, assuming that the flange formed an angle of 75° with a horizontal plane, or 15° from the vertical, then, with an adhesion of $\frac{1}{5}$, the load of 4 tons 1 cwt. on the outer leading wheel would prevent its rising unless forced against the rail by a side pressure equal to—

$\frac{1}{5} = 0\cdot2 = \text{cotangent } 78°\ 41'$; then

Tangent $(78°\ 41' - 15°\ 0') \times 4\cdot05$ tons $= 2\cdot02 \times 4\cdot05 =$ $8\cdot18$ tons, or, say,

$8\frac{1}{4}$ tons, or nearly three times the side pressure which would cause the other wheels to slide; so that, with this proportion of adhesion, there would have been a considerable margin of safety unless other forces were at work.

It is uncertain from the report whether or not the steam was shut off when the engine left the rails; but, in order to leave the case as simple as possible, it will be assumed that it was so, and that the engine was exerting no tractive force.[1]

[1] Appendix V.

Taking the speed at 15 miles an hour, or 22 feet per second, the centrifugal force was—

$$\frac{\overset{\text{Tons.}}{25 \cdot 65} \times 22^2}{32 \times 640 \text{ feet}} = \overset{\text{Ton.}}{0 \cdot 606},$$

or only about 12 cwt., which was considerably more than counteracted by the cant of $2\frac{1}{4}$ inches; the inward force due to which was

$$\frac{2\frac{1}{4} \text{ inches} \times 25 \cdot 65 \text{ tons}}{59 \text{ inches}} = 0 \cdot 97 \text{ ton},$$

or slightly exceeding 19 cwt., being about 7 cwt. more than the centrifugal force. As indicated by the loads on the wheels, the centre of gravity was about $\frac{1}{2}$ inch behind the centre of the driving axle; so, assuming the inner driving-wheel flange to have been pressed against the rail, the excess of cant would have thrown on the outer leading-wheel flange a side pressure of

$$86 \text{ inches} : \tfrac{1}{2} \text{ inch} :: 7 \text{ cwt.} : 0 \cdot 04 \text{ cwt.},$$

or about 5 lbs., which need not be taken into consideration. To this small extent, however, the engine would have been less likely to have left the rails had it been running at the speed at which the cant would balance the centrifugal force.[1] There is no probability that the engine was running at the very high speed at which the centrifugal force, after counteracting the cant, would have been sufficient to cause the flange to adhere: the accident cannot be accounted for under the conditions mentioned.

Assuming, however, that the adhesion, instead of $\frac{1}{5}$, or 20 per cent., had been 37 per cent. of the weight; then, in order to cause the other wheels to slide, the outer leading-wheel flange would have required to exert a side pressure equal to

$$0 \cdot 37 \times 15 \cdot 44 = 5 \cdot 7 \text{ tons},$$

or about 5 tons 14 cwt.; and this side pressure is just equal to that which, with 37 per cent. of adhesion, would cause the flange to adhere and rise over the rail, namely,

$0 \cdot 37$ being cotangent of $69° \, 42'$,

$$\text{Tangent } (69° \, 42' - 15°) \times 4 \cdot 05 \text{ tons} = 1 \cdot 41 \times 4 \cdot 05 = 5 \cdot 7 \text{ tons},$$

5 tons 14 cwt.

Thus the accident might have been caused by the rails being

[1] Transactions of the American Society of Civil Engineers, vol. vii., p. 107.

in such a condition that the adhesion was 37 per cent. of the weight, assuming that it happened at a place where the gauge was sufficiently tight to allow the flange of the inner driving wheel to come into contact with the rail before that of the inner trailing wheel. This might have been the case, as the curvature of the rail in the length of the wheel base amounted to about ½ inch.

The tractive force, the centrifugal force, and the cant have been left out of consideration, as their effect in this case was so small as hardly to influence the result.

It may have been noticed that the coefficient of the friction which would just cause the flange to adhere and mount the rail was assumed to be 37 per cent. in order more easily to explain the process of calculation, as the formula for ascertaining this coefficient is somewhat long, though quite elementary, being

$$\frac{N}{\left(\tan a \times \frac{M+N}{2}\right) + \sqrt{\left(\frac{M+N}{2\cos a} + \frac{M-N}{2}\right) \times \left(\frac{M+N}{2\cos a} - \frac{M-N}{2}\right)}} = \text{coefficient},$$

where N = product of the weight on the outer leading wheel multiplied by its distance from the wheel acting as fulcrum.

M = sum of the similar products of all the other wheels; and

a = angle formed by the working face of the flange and the plane of the wheel.

In the case in question—

N = 29 foot-lbs.

M = 110·567 foot-lbs.

a = 15°; and

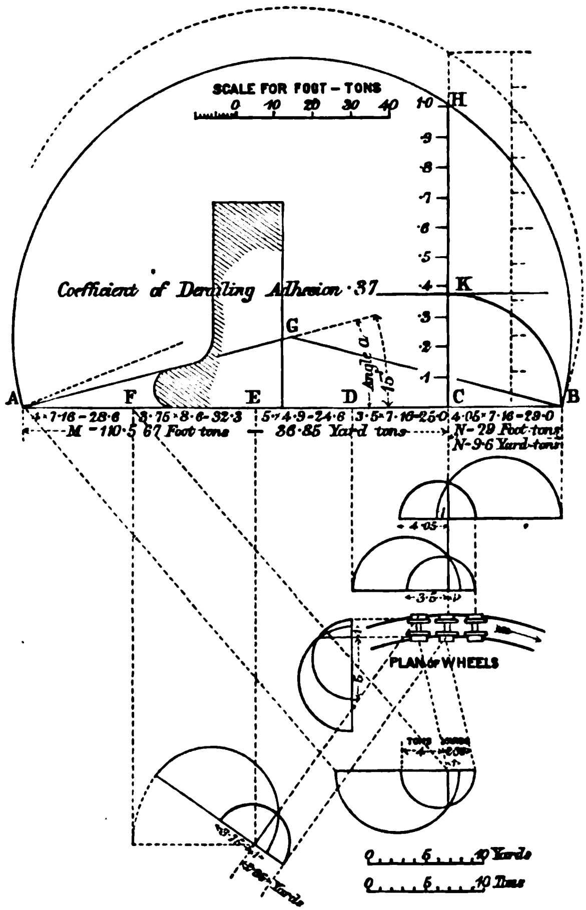
$$\frac{29}{(\tan 15^\circ \times 69{\cdot}78) + \sqrt{\left(\frac{69{\cdot}78}{\cos 15^\circ} + 40{\cdot}78\right) \times \left(\frac{69{\cdot}78}{\cos 15^\circ} - 40{\cdot}78\right)}} = 0{\cdot}37.$$

This coefficient may, however, be easily found by the following graphic method (Fig. 4, p. 12), of which the formula is merely the algebraic expression.

From the line A B cut off B C, representing to any convenient scale the number of foot-tons, foot-lbs., kilogrammetres, or any other units contained in the product of the weight on the outer leading wheel, multiplied by its distance from the wheel acting as fulcrum. From C A cut off C D, D E, E F, and F A, representing in like manner the products of the weight on each of the other

wheels, multiplied by its distance from the fulcrum. From A draw the line A G, making an angle B A G equal to the angle formed by the plane of the wheel and the face of the flange. From B draw B G, at the same angle intersecting A G in G. From G with the

FIG. 4.



radius G A or G B describe the circle A H B. From C draw C H perpendicular to A B, cutting the circle at H, and divide C H into one hundred equal parts. From C with the radius C B describe the circle B K, cutting C H in K; then will C K represent on the scale C H, the coefficient of the friction which will just cause the flange to adhere and mount the rail,—in this case 37 per cent.

When the plan of the wheels and their loads is given, the problem can be solved geometrically, without any arithmetical operation, as shown in the lower part of the diagram, where, for convenience of scale, the distances are measured in yards and the weights in tons by the same scale, so that the products are in yard-tons instead of foot-tons; but this of course does not affect the result.

The angle of the flange was just as likely to have been $22\frac{1}{2}°$ as 15°; and had it been so, the adhesion causing the wheel to mount the rail would have been 32 per cent., as indicated by the dotted circle and scale.

Had the flange of the leading wheel been lubricated so that the friction between it and the rail did not exceed that due to a greasy rail, or 18 per cent. of the pressure, as before stated, the wheel would not have risen by any pressure less than 2·12 times the load on the wheel, or about

$$4 \cdot 05 \times 2 \cdot 12 = 8 \cdot 58,$$

or 8 tons 12 cwt.; and to produce this side pressure, the adhesion between the treads of the wheels and the rails would be

$$\frac{8 \cdot 58}{15 \cdot 44} = 0 \cdot 55,$$

or 55 per cent. of the load, an adhesion greater than any that has been observed, and nearly one-half greater than that required to cause the flange to adhere when not lubricated.

If the springs of the leading wheels had been very flexible, so that the flange would rise beyond the point of maximum stability without noticeably increasing the load, the flange would have mounted the rail when the adhesion increased to 35 per cent.; and if, along with the flexible springs, the angle of the flange had been $22\frac{1}{2}°$, the engine would have left the rails with adhesion of 30 per cent. of the load.

If the coning of the trailing wheels just suited the curve so that the outer one slid only across the rail, the adhesion which would have caused the engine to leave the rails would have been 38 per cent.

Supposing the clearance to have been sufficient to allow the inner trailing-wheel flange to run against the rail, and the other circumstances as before, the adhesion which would have caused the leading wheel to mount the rail would have been 46 per cent. instead of 37, and the same would have been the result with the driving wheels flangeless; if, too, the leading-wheel flange had been lubricated, the adhesion of the treads which would cause it to rise would have been 82 per cent.

Had there been a guard-rail, as suggested by the Inspector, the

engine would not have left the rails unless the adhesion had been considerably greater than that stated above, as, before the flange of the outer leading wheel could have mounted the rail, the flange of the inner wheel would have come in contact with the guard-rail, relieving the outer wheel of part of the side pressure.

The foregoing case was selected for an example as being comparatively free from disturbing elements, and not on account of the percentage of friction causing the engine to leave the rails being exceptionally low. In another accident reported on, adhesion would have been less than 36 per cent. if the engine had been tight to gauge and about 46 per cent. if slack. In this last case the Inspector considered that the accident was due partly to some defect in the permanent way, and partly to the load on the wheel which left the rail being less than on the other wheels, the load on the leading wheels being 8 tons 12 cwt., on the driving wheels 12 tons 13 cwt., and on the trailing wheels 10 tons.

The following tables are calculated, as far as possible, exactly in a similar manner to the case given as an example, and are merely intended to indicate the comparative influences which variations in the proportions of an engine have in increasing or diminishing its tendency to leave the rails. These influences are measured by the coefficient of the friction which will just cause the flange of the outer leading wheel to adhere and mount the rail, referred to in the tables as the "coefficient of derailing adhesion."

The engine is supposed in all cases to weigh 30 tons. Where not otherwise stated, and not inconsistent with the other particulars, this weight is considered, when the wheels are level, to be equally distributed on the treads of six coupled-wheels 4 feet in diameter; the leading axle with its wheels weighing 1 ton, the driving axle and wheels $1\frac{1}{2}$ ton, and the trailing axle and wheels 1 ton, the deflection of each of the springs with its ordinary load being 2 inches. The load stated in the tables is this normal load, and not the load as altered by the rising of the outer leading wheel; but the alteration caused by this rising is allowed for as before.

Similarly the wheel-base is taken as 15 feet, the gauge 4 feet $8\frac{1}{2}$ inches, the angle between the face of the flange and the plane of the wheel 15°, and the treads of the wheels are assumed to be cylindrical.

In most cases the circumstances differ from the above in one particular only.

Where described as "tight to gauge," the curve and clearance are supposed to be such that the inner driving-wheel flange touches the rail. Where described as "slack to gauge," the curve is supposed to be easy enough, or the clearance and end-play of the

bearings to be sufficiently great, to allow the inner trailing-wheel flange to touch the rail; or the driving wheels are supposed to be flangeless, which would have the same effect.

As it is particularly desired to avoid exaggerating the danger, the circumstances as above stated are perhaps rather more favourable than would usually exist; for instance, the springs would generally be deflected more than 2 inches, and the angle of most flanges probably exceeds 15°. The centrifugal force also would generally increase the tendency to mount the rail, and in some cases this tendency would be increased by high winds and by oscillations.

In most cases the proportions are carried, in the tables, to their extreme limit in one direction, being that at which the derailing adhesion becomes less than one-fifth of the load, or 0·20. As might have been expected, this limit is generally far beyond what occurs in practice.

INFLUENCE of DISTRIBUTION of LOAD on the COEFFICIENT of DERAILING ADHESION.

Normal Load on			Tight to Gauge, with Inner Driving-wheel Flange touching Rail.			Slack to Gauge, with Inner Trailing-wheel Flange touching Rail; or with flangeless Driving Wheels.		
Leading Axle.	Driving Axle.	Trailing Axle.	Coefficient of Derailing Adhesion.	Coefficient of Derailing Adhesion, with Flanges lubricated.	Additional Tractional Resistance due to curve of 5 chains radius, in lbs. per ton, with adhesion = one-fifth of load.	Coefficient of Derailing Adhesion.	Coefficient of Derailing Adhesion, with Flanges lubricated.	Additional Tractional Resistance due to curve of 5 chains radius, in lbs. per ton, with adhesion = one-fifth of load.
Tons.	Tons.	Tons.			Lbs.			Lbs.
1	28	1	0·12	0·10	4·48	With these loads the adhesion of the driving wheels prevents the trailing-wheel flange from touching the rail.		
2	26	2	0·18	0·19	4·96			
3	24	3	0·24	0·28	5·47			
4	22	4	0·28	0·35	5·98			
5	20	5	0·31	0·41	6·50			
6	18	6	0·33	0·47	7·05			
7	16	7	0·35	0·51	7·58	0·40	0·63	9·56
8	14	8	0·36	0·55	8·11	0·44	0·75	9·85
9	12	9	0·38	0·58	8·64	0·48	0·87	10·11
10	10	10	0·39	0·61	9·20	0·52	1·00	10·50
11	8	11	0·40	0·64	9·74	0·55	1·14	10·84
12	6	12	0·41	0·66	10·28	0·59	1·28	11·23
13	4	13	0·41	0·67	10·82	0·63	1·43	11·35
14	2	14	0·42	0·70	11·35	0·66	1·61	11·79
15	0	15	= four wheels.			0·70	1·79	11·99
8	14	8	0·36	0·55	8·11	0·44	0·75	9·85
8	11	11	0·34	0·48	9·00	0·46	0·82	9·92
8	8	14	0·32	0·43	9·90	0·49	0·90	9·89

INFLUENCE of the WIDTH of GAUGE on the DERAILING ADHESION.

Width of Gauge.	Coefficient of Derailing Adhesion.	
	Tight to Gauge, with Inner Driving-wheel Flange touching the Rail.	Slack to Gauge, with Inner Trailing-wheel Flange touching Rail, or with flangeless Driving Wheels.
Feet. Inches.		
2 0	0·4	0·55
3 0	0·41	0·54
4 8½	0·39	0·52
7 0	0·36	0·49
35 0	0·20	0·29
75 0	..	0·20

INFLUENCE of the LENGTH of WHEEL-BASE on DERAILING ADHESION on a CURVE of 5 CHAINS (330 FEET) RADIUS.

Length of Wheel-base.	Coefficient of Derailing Adhesion.	
	Tight to Gauge, with Inner Driving-wheel Flange touching the Rail.	Slack to Gauge, with Inner Trailing-wheel Flange touching Rail, or with flangeless Driving Wheels.
Feet.		
1	..	0·20
2	0·20	0·29
5	0·29	0·41
10	0·36	0·49
12	0·38	0·50
15	0·39	0·52
20	0·40	0·53
25	0·41	0·52
30	0·42	0·52
35	0·42	0·50
40	0·41	0·48
50	0·40	..
200	0·20	0·20

INFLUENCE of the NUMBER of WHEELS on the DERAILING ADHESION.

Number of Wheels.	Coefficient of Derailing Adhesion. Tight to Gauge, with the Flange of the Inner Wheel in the middle, or nearest the middle, of the length touching the Rail.	Coefficient of Derailing Adhesion. Slack to Gauge.
4	0·70	0·70
6	0·39	0·52
8	0·39	0·39
10	0·29	0·35
18	0·20	0·24

It will be noticed that the danger is greatest in engines which have an axle in the middle of the length of their wheel-base.

INFLUENCE of the ANGLE of FLANGE on the DERAILING ADHESION.

Complement of the Angle between the working face of the Flange and a horizontal Plane.	Coefficient of Derailing Adhesion. Tight to Gauge with Inner Driving-wheel Flange touching the Rail.	Coefficient of Derailing Adhesion. Slack to Gauge, with Inner Trailing-wheel Flange touching Rail, or with flangeless Driving Wheels.
° ′		
0 0	0·53	0·68
5 0	0·48	0·62
10 0	0·43	0·56
15 0	0·39	0·51
16 30	0·37	0·50
20 0	0·35	0·46
22 30	0·33	0·44
25 0	0·31	0·42
30 0	0·28	0·38
35 0	0·25	0·34
40 0	0·22	0·30
45 0	0·19	0·27
50 0	..	0·23
55 0	..	0·20

Restricting the subject strictly to six-wheeled engines with parallel axles, and referring to such engines only, the following inferences may be drawn from the foregoing remarks:—

1. That the danger of leaving the rails increases when the adhesion increases.

2. That the greater the portion of the weight of the engine resting on the leading wheels, the less is the danger of leaving the rails at low speeds.

3. That when tight to gauge the danger is increased to the greatest extent by augmenting the load on the trailing wheels, at low speeds.

4. That when slack to gauge, or the driving wheels flangeless, or the radius of the curve large, the greatest danger is brought about by increasing the load on the driving wheels.

5. That the danger increases when the radius of the curve decreases; but, at low speeds, the danger increases very slowly until the curvature becomes such that the inner driving-wheel flange is brought into contact with the rail, when the danger increases suddenly; and the danger is aggravated by tightness of gauge.

6. That this sudden increase of danger is obviated by making the driving wheels flangeless; and that flanges on the driving wheels are worse than useless.

7. That the danger increases when the gauge is widened in proportion to the length of the wheel-base.

8. The danger of leaving the rails diminishes when the length of wheel-base increases in proportion to the width of gauge; but when the length of wheel-base increases in proportion to the radius of the curve, the danger increases; so that there is a certain length of wheel-base giving a minimum of danger: but, within the limits of practice, the longer the wheel-base, the less the danger of leaving the rails. Nevertheless the tractional resistance always increases with the wheel-base.

9. The danger is increased by increasing the number of wheels; but the tractional resistance diminishes when the number of wheels is increased.[1]

10. That the danger increases when the angle formed by the working side of the flange and the plane of the wheel increases beyond that necessary to keep the rounded edge of the flange clear of the rail on the sharpest curve it has to run on.

11. That the danger is increased by enlarging the diameter of the leading wheels.

12. That the danger is increased by diminishing the projection of the flange.

13. That the danger is increased by making the springs of the leading wheels more flexible.

[1] This paragraph does not come under the restriction of six-wheeled engines only.—J. M.

14. That the danger is considerably diminished by lubricating the flanges of the leading wheels; and increased by applying sand to these wheels.

15. That, when the centre of gravity is behind the driving axle, the danger is increased by an excess of super-elevation of the outer rail beyond that required to counteract the centrifugal force.

16. That the danger may be increased by shutting off steam and reducing speed while running on a curve.

17. That, although one engine or carriage may run round a curve with less tractional resistance than another, it is not therefore necessarily in less danger of leaving the rails. In many cases it is quite the reverse.

Lastly. That, assuming an adhesion of 40 per cent. of the weight to be possible, some engines of not unusual proportions have, as regards leaving the rails, a very narrow margin of safety: so narrow that, in any other matter connected with the running of a train, a similar margin of safety would be considered insufficient.

The Author, in conclusion, desires to acknowledge his obligations to Messrs. Adams, Bromley, Dean, Drummond, S. W. Johnson, Kirtley, Stirling, Stroudley, and Webb, MM. Inst. C.E., for sections of tires and other information supplied for the purposes of the Paper.

The Paper is accompanied by several diagrams, from which the woodcuts in the text have been prepared.

[APPENDICES.

APPEND[illegible]

APPENDIX I.

The Paper was suggested by an unintention[illegible] of the driving wheels of a six-wheeled engi[illegible] [illegible] This was overdone; a[illegible] [illegible] to another line of [illegible] [illegible] a curve, mounted the rail. The spri[illegible] [illegible] and the engine ran safely aft[illegible] The [illegible] were dry, and, owing to the nature of [illegible] [illegible] sand, so that probably the adh[illegible] [illegible]

[illegible] seemed not only to point to the n[illegible] [illegible] of the weight of a six-wheele[illegible] [illegible] rather the outer one of them, to guide th[illegible] [illegible] that it would be desirable to [illegible] as it appeared possible that, in pr[illegible] [illegible] and may account for many hitherto une[illegible]

The most [illegible] way of ascertaining this [illegible], but an exhaustive series of su[illegible] [illegible] which would require the resources of [illegible] In the absence of such experiments, and to a[illegible] [illegible] it may therefore be advisabl[illegible] [illegible] by inferences from experiments mad[illegible] [illegible] experience of accidents recorded in the Board o[illegible]

The subject is not devoid of public interest, as, [illegible] of Railway Accidents in 1880, the d[illegible] [illegible] passenger trains, or parts of passenger tra[illegible] [illegible] than those from any other class of [illegible] [illegible] at p. [illegible]

APPENDIX II.

A single narrow wheel rolling freely on a level surfac[illegible] [illegible]: but it is turned out of that line so as to [illegible]; and, when the axis is kept in th[illegible] [illegible] the wheel traverses that curve with very [illegible] the wheel traverses that curve with very [illegible] keyed fast on the ends of the sa[illegible] wheels of the same size, keyed fast on the ends of the sa[illegible] [illegible] in a straight line at right angles to their ax[illegible] [illegible] of that line without causing one wheel to slid[illegible] When only the outer one of two such wheels is guided [illegible]

[illegible] "Railways of Great Britain and Ireland," by Fra[illegible] [illegible]

[illegible] Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 10.

the inner wheel outruns the outer until the axle becomes parallel with the rail, or at such angle that the wheels cease to revolve. To enable two wheels on the same axle to run round a curve without sliding, it is necessary to make one of them larger than the other, or to make one or both of them loose on the axle.

Two wheels, mounted one in front of the other (as in a bicycle), on parallel axles, also roll in a straight line at right angles to their axes, and any deviation from this straight line can only be accomplished by causing one wheel to slide sideways. If two such wheels on parallel axles are caused to run in a curve by a rail or guide acting on the front wheel, that wheel on first entering the curve slides sideways in an inward direction towards the centre of the curve, but still with a direction giving it a tendency to run outwards. The hind wheel by this motion is turned inwards, until the axis assumes a radial direction, when it follows the front wheel, though not exactly in the same track, being nearer to the centre of the circle. This seems to be the only combination of equal and parallel wheels in which, the front wheel being guided in a curve, the other or others take up a definite relative position, whether they are loaded equally or unequally. In all other combinations, the positions of the wheels depend upon their loads and the state of the surfaces as regards friction, owing to the sometimes conflicting tendencies of all the wheels, except the front ones, to run with their axes radial, and of all the inner wheels to outrun the corresponding outer ones.

To allow two wheels, one in front of the other, to travel round a curve without slipping, the axles must be made to converge towards the centre of that curve. When three wheels, in the same plane, are mounted on parallel axles, and the front wheel is caused to move in a circle, the middle and hind wheels have each a tendency to run with its axis in a radial direction; but, as it is impossible that they can both do this, they take up positions such that their plane forms a tangent to the curve, either at the more heavily loaded of the two wheels, or at a point somewhere between them, nearer to the more heavily loaded wheel. Thus a carriage on four or more equal wheels, fixed on two or more parallel axles, will, on a plane surface, run in a straight line, and can only be turned out of that line by at least two of the wheels being made to slide backwards and forwards, and at least two to slide sideways, one of which is at the same time sliding backwards or forwards; so that at least three wheels (or rather all the wheels but one) must be sliding.

As stated in a former discussion, "A model carriage, having two pairs of wheels fixed on parallel axles, the diameter of the wheels on one side of the carriage being less than those on the other side,—this model carriage being placed on a board, and one end of the board lifted until gravity caused the carriage to run down,—it was found that the carriage ran straight, and not, as might have been expected, in a curve."[1] This, however, is the case only when the carriage has a comparatively long wheel-base. When the wheel-base is less than the width between the wheels, the carriage travels in a curve. The shorter the wheel-base, the more nearly does the curve seem to approach that proper to the cone formed by a pair of wheels, and the carriage turns in this direction even although the wheel-base is longer on the side next the small wheels than on the other side. The model thus seems to travel in the direction which causes the smallest amount of sliding, whether this sliding takes place in the direction of the planes of the wheels or of their axis; that is to say, along or across the rails. Therefore, in a carriage

[1] Minutes of Proceedings Inst. C.E., vol. xxiii., p. 428.

or engine with a long wheel-base, it would be a greater advantage to have the axles radiate than the wheels to run loose on the axles; while, with a broad gauge and a very short wheel-base, it would be better to have loose wheels than radiating axles. This is more evident if the proportions of wheel-base and gauge are carried to their extreme limits.

Suppose the wheel-base of a four-wheeled carriage to be the longest possible, namely nearly equal to twice the radius of the curve on which it runs, and the gauge to be very narrow, then, if the axles are parallel, the wheels will be nearly at right angles to the rails, and will not roll, their whole motion being sliding sideways; while, if the axles are radial, the wheels on each, though of the same size, being close together, will roll round the curve without much friction.

Suppose the gauge to be the widest possible, namely nearly equal to the radius of the curve, and the wheel-base extremely short, then the axles will be so nearly radial, that the wheels will roll round the curve with very little sliding in the direction of their axes, or across the rails; but if they are all of one size, to enable them to run without an excessive amount of sliding in the direction of the rails, they would require to be made loose on their axles, since the inner wheels, being close to the centre of the curve, have hardly any distance to travel, and so hardly need revolve.

When a carriage or engine with four equal wheels on two parallel axles is running on a curve at low speed (or at such speed that the cant of the rails balances the centrifugal force), the carriage not being attached to a train, and there being no play between the flanges of the wheels and the rails, then both axles are parallel to a radius half-way between them, and none of the wheels are parallel with the rails on which they run, the leading wheels standing across the rail in a direction giving them a tendency to run outwards, and the trailing wheels at an equal angle in the opposite direction, with a tendency to run inwards. Suppose, now, the flanges were removed from all the wheels, the carriage would run straight forwards at a tangent to the curve, and the path traced by the rail on the circumference of each wheel would, for a short distance, be a helix or screw, with an obliquity or pitch corresponding with the angle formed by the wheel and rail. If the helix is right hand in the case of the leading wheels, it will be left hand in that of the trailing wheels.[1] The wheels, however, being prevented by their flanges from running straight on, slide across the rails to the extent of the pitch of the helix during each revolution, the leading wheels sliding inwards towards the centre of the curve, and the trailing wheels outwards. The flange of the outer leading wheel is thus forced against the rail by a pressure sufficient to cause both the leading wheels to slide inwards across the rails; and the flange of the inner trailing wheel is acted on by a pressure sufficient to cause both trailing wheels to slide outwards across the rails.

Owing to the difference of the lengths of the inner and outer rails, either the wheels on the inner rail, besides sliding across the rail, will also slide backwards, or those on the outer rail forwards. The former is probably the case in ordinary working, when an engine with all wheels coupled is dragging a load, and the latter when running by momentum or down an incline with steam shut off. For the present purpose, however, it is only necessary to consider which will be the case when the flange of the outer leading wheel is in the act of mounting the rail. At that time, the whole of the load on that wheel is

[1] Minutes of Proceedings Inst. C.E., vol. xxvi., p. 359.

borne by the adhesion of its flange, and the tread is relieved of all load and adhesion, so that the wheel is running on a diameter larger than that of the tread, and larger, on almost any curve, to a sufficient extent to allow the inner wheel to revolve at the speed due to its tread, running on the shorter length of the inner rail. If all the wheels are coupled, the inner trailing wheel also revolves at the speed due to its tread, leaving the outer trailing wheel revolving at a speed slower than that due to its tread, running on the greater length of the outer rail. In this case it is probable that this one wheel slides forward on the rail, the whole of the wheels thus revolving at the speed due to their treads, travelling over the length of the inner rail.

The outer leading wheel thus slides forwards, and at the same time inwards across the rail; the inner leading wheel slides only inwards across the rail; the outer trailing wheel slides forwards and outwards across the rail; the inner trailing wheel slides only outwards across the rail. The sliding motions of the wheels are thus similar to those which would take place if the engine, without moving forwards, revolved horizontally about a centre situated half-way between the two inner wheels; and the distance which any wheel slides along and across the rail while the engine makes a complete revolution, is the same, or nearly the same, as that which it slides while the engine is running round a complete circle of any diameter, however large. Thus the energy expended in overcoming the friction of the treads of the wheels in going round a circle is a constant quantity, whatever may be the size of that circle. From this it follows that, as generally admitted, the additional tractional resistance due to that friction varies inversely as the radius of the curve; but it does not follow that the tendency to leave the rails increases in anything like this ratio.

When by the force of traction the inner wheels are caused to slide backwards, the sliding motions of the wheels will take place around a point situated between the two outer instead of the inner wheels.

Again, when the clearance between the flanges of the wheels and the rails is sufficient, the trailing axle runs forwards until it assumes nearly the direction of a radius to the curve. It may be slightly in advance of this position, or slightly behind it, the precise position depending upon the comparative loads on the wheels, and the proportion of wheel-base to gauge. In this case, supposing as before that the outer wheels slide forwards, the outer leading wheel slides inwards across the rail and at the same time forwards; the inner leading wheel slides only inwards across the rail; the outer trailing wheel slides only forwards; and the inner trailing wheel does not slide at all. The sliding motions of the wheels on the rails are thus nearly the same as those which would take place if the engine revolved about the inner trailing wheel. The flange of the inner trailing wheel is thus relieved of all side pressure, and the only flange pressing against the rail is that of the outer leading wheel, which must thus exert the whole of the side pressure required to cause the sliding of its own wheel, of the inner leading wheel, and of the outer trailing wheel. The leading wheels now run at a greater angle with the rails than they did when the gauge was tight; and the distance which the wheels slide in going round a circle is greater.

A carriage with four, six, or more wheels on parallel axles, does not absolutely require flanges on any except the leading wheels, which being thus guided, the other wheels will follow them, and, if wide enough, will keep on the rails.[1]

Thus, when there is clearance enough, or the curve is easy, the whole of the flange friction comes on the outer leading wheel.

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[1] Minutes of Proceedings Inst. C.E., vol. xxxi., p. 403.

APPENDIX III.

In the case of a six-wheeled engine running, without exerting tractive force, with the inner driving-wheel flange in contact with the rail, it is even more probable than in the case of a four-wheeled engine, that the outer wheels slide forwards, and that the inner ones do not slide backwards. Assuming the wheels to be nearly equally loaded, the weight upon the driving wheels is not sufficient to enable their adhesion to cause them to form a fulcrum to move the trailing wheels across the rails. Thus, the inner driving-wheel flange is pressed against the rail causing additional adhesion, to overcome which, in the event of the inner driving wheel sliding backwards, an additional pressure would be exerted by the flange of the outer leading wheel. This in turn causes an additional pressure on the inner driving-wheel flange, so that the two wheels act and react upon each other, and the side pressure on the inner driving-wheel flange causes the adhesion of that wheel to be greater than that of the outer one.

APPENDIX IV.

With a tire having a flat or conical flange sharply joined to a cylindrical or slightly conical tread, or with almost any tire running on a rail considerably rounded on the top there are two points of contact, one between the top of the rail and the tread vertically under the wheel's axis, and the other between the side of the rail and the flange some distance in advance of the axis when running towards the rail on a curve.

With a tire whose flange is joined to the tread by a curve of considerably greater radius than that of the rounded corner of the rail, or with almost any tire running on a flat-topped rail, the two points of contact merge into one when the wheel is running towards the rail on any ordinary curve, the wheel resting on the rounded corner of the rail at some point determined by the proportion of weight to side pressure, and this point is slightly in advance of a perpendicular from the wheel's axis. In this latter case flange-friction can hardly be said to have a separate existence.

APPENDIX V.

Had the engine been exerting a considerable amount of tractive force, the case would have been altered, perhaps somewhat as follows:—The tractive force being, as regards the adhesion of the wheels, equivalent to a strain pulling the wheels backwards, the inner driving and trailing wheels would slide backwards instead of the outer ones forwards. The backward pull would therefore relieve the outer leading wheel of the side pressure required to effect the longitudinal sliding motion, leaving only that required to effect the cross sliding. This pressure would thus be reduced—

For the outer leading wheel . .	$0 \cdot 0\ (4 \cdot 05 \times 7 \cdot 16 = 29 = N)$	$= 0 \cdot 0$
" inner " " . . .	$0 \cdot 2\ (3 \cdot 5 \times 7 \cdot 16 = 25 \cdot 060) \div 7 \cdot 16$	$= 0 \cdot 70$
" outer driving " . .		$= 0 \cdot 0$
" inner " " . .		$= 0 \cdot 0$
" outer trailing " . . .	$0 \cdot 2\ (3 \cdot 75 \times 7 \cdot 16) \div 7 \cdot 16$	$= 0 \cdot 75$
" inner " " . . .	$0 \cdot 2\ (4 \cdot 0 \times 7 \cdot 16) \div 7 \cdot 16$	$= 0 \cdot 80$
	Tons	$2 \cdot 25$

Assuming, however, that the drag-link was attached to the engine at a considerable distance behind the driving axle, then the backward pull would give this part of the train a tendency to straighten out, and so increase the side pressure on the outer leading wheel. Assuming the backward pull to be equal to one-fifth of the weight of the engine, or $\frac{25 \cdot 65}{5} = 5 \cdot 13$ tons, acting at 11 feet behind the driving axle, where the coupling would form an angle of about 179° with the centre line of the engine, it would cause an inward pressure at the coupling of $5 \cdot 13 \times \sin. 179° = 0 \cdot 089$ ton, which, supposing the engine to be revolving about either driving wheel, would cause an additional outward pressure on the outer leading-wheel flange of $\frac{0 \cdot 089 \times 11 \text{ feet}}{7 \cdot 16 \text{ feet}} = 0 \cdot 14$ ton, which added to $2 \cdot 25$ tons brings up the pressure to only $2 \cdot 39$ tons. Thus the side pressure on the outer leading-wheel flange is considerably less when an engine is exerting its tractive force, than when running with steam shut off.

[Discussion.

Discussion.

Mr. Wells Owen. Mr. G. WELLS OWEN was reminded by the Paper of the story of the man who was put in the stocks, and whose friends kept on saying, "But they cannot do it." Whilst his oft-repeated cry was, "But they did do it." Theoretically, according to the Paper, every six-wheeled engine ought to run off the rails; but the fact remained that they did not do so. There were very many circumstances in practice which prevented machinery and materials acting in the way in which they were theoretically supposed to do. He did not intend to enter into the mathematical part of the question, but merely to say that he thought it would be interesting if those who took part in the discussion would enter as much as possible into the causes which prevented engines acting as they should do according to the theory set out by the Author.

Mr. Walter Browne. Mr. WALTER R. BROWNE said the Author had stated that "The tendency which a wheel has to mount the rail on a curve is evidently caused by the adhesion or friction between the rail and the flange of the wheel." He was taught many years ago at Cambridge that whenever one saw the words, "it is evident," or, "it is easily seen," in a proof, particular attention should be paid to that sentence, because one might be pretty sure that there lay the difficulty of the whole; and the sentence he had just read seemed to him no exception to the rule. Generally when a man said, "It is evident," what he really meant was, that it was not quite evident to his own mind, but he hoped it would be so to the minds of other people. He did not at all say that was the case with the Author; but he wished, for the sake of those who had not studied the subject so deeply, that he would, in his reply, explain the grounds on which he asserted that the tendency to mount the rail was caused by adhesion or friction between the rail and the flange of the wheel. To him it was difficult to see how friction could cause any such mounting. Friction tended to prevent action in almost all cases, and it certainly seemed a paradox to state that it tended to produce that particular action. Further on, the Author stated that if there was no friction, an engine would never run off the rails. The reverse of that appeared to be, he would not say evidently, but demonstrably true. Taking any one of the tire-sections shown by the Author, and supposing that there was absolutely no friction whatever between the wheel and the rail, then, if the wheel ran round a curve, it followed that the

Mr. Walter Browne.

centrifugal force, as it was generally called, acting outwards on the wheel, would have a component at right angles to the rail, and that component would have another along the tangent between the wheel and the rail-head; and as there was no friction, by hypothesis, to stop it, it was evident that the wheel would move outwards upon the rail-head (he assumed that there was no weight to keep it down), and since the flange was nowhere vertical, would continue to rise until it mounted completely over the rail. He could see no possible way out of that difficulty; therefore, if there was no friction, an engine would always run off the rails at a curve; and therefore it was at least difficult to see how the existence of friction could tend to make an engine mount the rails. There was a sentence (p. 5) which might possibly be intended for the Author's explanation of his meaning: "The point of contact between the outer leading-wheel flange and the rail is in advance of a perpendicular from the wheel's axis, so that the motion of the wheel at that point is downward, imparting a downward pressure to the rail, and an upward pressure to the wheel. Thus, when the adhesion between the flange and the rail is greater than the weight upon the wheel, the flange would rise and mount the rail." That did not appear to him to be happily expressed, but he presumed that what the Author meant was, that the flange being in contact with the rail, there was a tendency for the wheel to turn, not about the point of contact between the tread and the rail, but about the point of contact between the flange and the rail. It was not that the flange itself would rise at this point—which seemed to him impossible; but that the wheel itself would rise, as a whole, over that point, and in so doing would mount to that extent upon the rail. But if it was considered that the whole weight of the car was resting on the tread, and not on the flange, and that if that action occurred the tread must leave the rail altogether, it seemed impossible to suppose that this tendency, whatever it might be, had in practice any real effect.

There was, however, a cause for the derailment of engines which the Author seemed to have ignored, and which appeared to be one of those practical points to which Mr. Owen had called attention. He had often watched an express train going at full speed through a station-yard where there were many crossing points, and many things to make the line uneven; and had seen the wheels lunging and swinging and banging from side to side as they crossed the points, so that the engine seemed at one time coming straight towards him, and at another going 50 feet to the right or the left of him. That was enough to show how an engine might leave

Mr. Walter Browne. the line, independently of any question of friction. Whenever there was any inequality in the side of the rail, which the flange of the wheel struck, it gave the whole engine an impulse inwards; it then struck against the opposite rail and flew back again, and that oscillation went on for some little time. If this lateral oscillation was combined with a vertical jolt, as for instance if one rail at a joint was lower than the other, then derailment was certain to occur, and he contended that derailment was in all cases due to some such cause as this, and not to friction at all. That effect seemed to be fully recognised by practical men, as, indeed, might be expected. It was stated, with regard to the particular instance that the Author had chosen as the basis of his elaborate calculations as to the exact amount of adhesion necessary to make an engine mount, that the inspector reported: "The road did not gauge very evenly . . . being in some places as much as $\frac{9}{16}$ inch slack, and in others exact to gauge." The inspector went on to say, "I am of opinion that this accident was due to the want of a proper check-rail at this curve of under 10 chains radius, and to the somewhat slack state of the permanent way." It was obvious that if the gauge differed so much within so short a distance, that in itself constituted a considerable obstacle tending to throw the engine sideways; and it was a cause nearly independent of the speed at which the engine was going, accounting therefore for cases of derailment at low speed, which the Author thought it so difficult to explain, because the centrifugal force was not sufficient.

He would conclude by drawing the attention to a discussion that had recently taken place in America upon an important part of the question which the Author had hardly touched upon, namely, the question of coning the wheel tread. All the sections shown were coned, and he supposed that every wheel running on an English railway was coned: nevertheless the question whether it was a right thing to do could not be considered as altogether settled. Mr. Crampton, a high authority, held that the coning of wheels was a mistake. Mr. Haswell, at Vienna, had the whole of his rolling-stock fitted with cylindrical wheels. In America a very large number of instances were quoted in which cylindrical wheels had worked perfectly well, and even in which the taking off of the cone and turning down the tire to a cylinder had proved beneficial. The Master Car-builders' Association had discussed the question, and the discussion was contained in their last report. He might be permitted to read a few words that had fallen from a gentleman who had paid as much attention to railways as almost any one—Mr. M. N.

Mr. Walter Browne.

Forney, of New York. "Any one who will undertake to look into this subject and examine it analytically will find that it is one of the most complicated things relating to railroad construction. I have made more graphical diagrams, and more drawings of sections, and tangents, and rails, and various other things, in order to get the matter clearly before my own mind, than, I presume, any of the members here would suppose it was possible to devote to so simple a subject. The precise relation which the flange bears to the rail, in going round a curve, is a thing which it is extremely difficult to understand clearly in your own mind." With those words he fully agreed, and he therefore hailed the Paper under discussion as showing the subject was attracting attention in England; but he hoped the Author would give it still further consideration, and then perhaps he might see cause to modify some of the conclusions at which he had arrived.

Mr. Grover.

Mr. J. W. Grover said there was a sentence in Appendix I. to the Paper which seemed to call for special attention. It was stated in the Board of Trade Returns for 1880 that more deaths had resulted from passenger trains, or parts of passenger trains, leaving the rails than from any other cause. The Paper was very suggestive, but any one looking at the diagrams would see that there were many matters still unsolved which it was desirable to have explained. The whole subject was one of much importance, but it had been greatly neglected. About the year 1853 the Emperor Napoleon III. instituted a Commission for investigating the question, and there was an elaborate series of reports on it in the "Annales des Ponts et Chaussées," third series. Fourteen years ago he endeavoured to bring the reports before the Institution, but was unsuccessful. Perhaps the subject was not then ripe; it was certainly more ripe for discussion at the present time than it was then. With the increased size of rolling-stock and greater length of wheel-base there had been a tendency to reduce the radii of the curves; consequently the two poles were approaching each other. The question was one which had not been thoroughly considered. There was an element of safety shown by the diagrams, and in all carriages and wagons which were used on railways, viz., the fact that the wheels were keyed on to the same axle. In 1871 he had an engagement in Woolwich Arsenal, and he made a series of experiments there, which were published in "Engineering," March 24th, 1871, showing the remarkable manner in which the derailment of a truck was facilitated by the unkeying of the wheel upon the axle. Why that should be it was difficult to say, but the simple fact remained, and it was one

Mr. Grover. which it was important to bear in mind, that while two wheels were firmly keyed upon one axle there seemed to be some law which prevented the one from mounting and climbing over the outside rail in passing round a curve. He found it was possible to keep the trucks upon the line by making the axles radiate, if he made the wheels loose; but he did not find it possible to keep them on at all without radiation if he gave the outer wheel the independent motion which it had by unkeying it off the axle. He thought it could be explained thus: that the moment the outer wheel began to mount the rail it travelled on a much larger circumference than the inner one. There was a partnership between the two wheels so long as they were keyed on the same axle; and the inside partner, on the smaller diameter, objected strongly to the outer partner travelling faster than itself; consequently it gave a retarding movement through the axle, and prevented the outer wheel from mounting the rail. He thought that element more than anything else contrived to keep the carriages on the line. But, going carefully through the Paper, a difficulty was apparent which seemed almost insurmountable. There was, for example, the fact that an engine did go off on a 640-feet curve; but then, again, there was the still more startling fact, which might be assumed, although it was not stated, that the engine during a great part of its life must have been constantly going round curves in station yards of very much smaller radius than that of the curve where it ultimately went off. Of course the answer was that it did go off at that particular curve; but it was astonishing that it should not have gone off on the sharpest curve that it went round, where the tendency to derailment must have been greater. With regard to the coefficient of friction which had been assumed in the Paper, he had looked at Rennie's experiments in the "Philosophical Transactions,"[1] and found that he gave a coefficient as high as 0·409, with 560 lbs. pressure to the square inch; and with a less pressure the coefficient was less. He therefore thought that the Author, in assuming that 0·37 was possible and practicable, was certainly not exceeding the bounds of possibility. With regard to the fact of the inner wheel skidding if the outer wheel passed round a curve, there was no doubt that to a large extent there was in that an element of friction. He had examined the matter mathematically, and found that as the wheel-base was to the gauge so

[1] "Experiments on the Friction and Abrasion of the Surfaces of Solids," by George Rennie, Phil. Trans. 1829, p. 143.

was the resistance caused by the friction of the flange being at the angle to that caused by the skidding of the inner wheel. Thus, with a wheel-base of 20 feet, and a gauge of about 4 feet $8\frac{1}{2}$ inches, there would practically be four times as much tractional resistance from the flange friction as from the skidding of the tire inside. Therefore, for practical purposes, that skidding of the wheel might be neglected. The serious and vital thing was the tendency which the wheel had, in consequence of its obliquity, in passing round a curve, to run off. There was a remark in the Paper "That the danger increases when the radius of the curve decreases." "The danger of leaving the rails diminishes when the length of wheel-base increases in proportion to the width of gauge; but when the length of wheel-base increases in proportion to the radius of the curve, the danger increases; so that there is a certain length of wheel-base giving a minimum of danger: but, within the limits of practice, the longer the wheel-base the less the danger of leaving the rails." He thought that the Author's formula and the whole argument in the Paper were directly contrary to that experience. The wheel-base was a chord drawn across any point of a curve, and the larger the wheel-base the greater was the versed-sine, and the greater was the angle made by the exterior wheel in passing round the rail. Considering the wheel-base as equal to twice the radius, the condition then was of a wheel standing square to the rail, and having a tendency to go straight over. Now conceiving the wheel-base to be infinitely small, then the wheel would be perfectly plane and parallel to the rail. Between those limits there was, no doubt, a proportion beyond which it was evident that, with an increased wheel-base, the danger of running off the curve was increased. The Author had clearly shown that as the wheel-base was increased, so also was the tractional resistance round the curve. It was absurd to say that the danger was not at the same time increased. It was well known to practical men that with sharp curves the rigid wheel-base must be reduced, while with good curves a long flat wheel-base was possible. He desired to call attention to the great danger of the present practice of enormously increasing the rigid wheel-base under railway carriages. In the reports of railway accidents it would be found that there were an immense number of cases in which carriages had gone off at railway stations and at crossings. The reason was that those long carriages, many of them with 22-feet wheel-base, going round curves of 300 or 400-feet radius, had a great tendency to mount the outer rail. The wheel ground the outer rail until Mr. Grover.

Mr. Grover. it got hold of something, and the check-rail, being a little slack, allowed it to do so, and off it went. There was a place at Leeds where two trains went off one week after the other. It was a question demanding serious consideration, whether by radial axles a long safe wheel-base could be had. It was certainly worth some effort to obtain a radial axle. He had lately seen a terrible accident at Birkenhead on a tram-road, resulting from a fixed wheel-base and a rigid axle. Such axles could not relieve themselves, or get adjusted to the curves; they had to grind round the curves as best they could. At the place to which he referred there was a somewhat steep gradient, and at the bottom a sharp curve, and in going round that curve the car ran off, fell over, and sent the passengers on to the pavement, the result being that twenty or thirty persons were killed or wounded. A similar accident shortly afterwards took place at Blackburn. Between thirty and forty persons were wounded and two killed from similar causes within three weeks. He thought that public attention ought to be directed to the subject.

Mr. Langley. Mr. A. A. LANGLEY agreed that a long wheel-base increased the difficulty of an engine getting round curves. A short time ago some ten-wheeled engines were put on the Great Eastern Railway. They went round sharp curves very well so long as the permanent way was old; but when the permanent way was relaid with new and heavier materials, and the sleepers were firmly bedded in the ballast, the engines went off the line. The first time this occurred he thought there had been some neglect on the part of the man in charge of the relaying, but he found that the road had been relaid properly, with the super-elevation of the outside rail, and with the extra width of gauge for the curve. On investigating one case, it appeared that one of these engines flattened the curve in its progress, making a 5-chain curve into a 7-chain curve along its wheel-base; the sleepers moved out of their place backwards and forwards as much as $\frac{1}{2}$ inch in the ballast. When, however, the sleepers were firmly secured, and the 5-chain curve was maintained, the engine mounted the rails. This kind of action he believed to be going on in many cases where least expected. He always keyed the rails outside, as he was of opinion that this plan tended to keep the engines on the line. He had lately been taken over a line of railway which had the same description of rails, chairs, and other materials throughout its length; but portions of it were keyed outside, and portions inside. Any one travelling on this line could tell which portions were keyed inside, as the metal to metal on the outside caused a rigidity that did not exist with

the outside keying. An objection had been made to the outside keying, that a number of keys might drop out, and so liberate the rail and cause an accident; but he kept the ballast boxed up on the outside, nearly to the level of the rails. The keys did not then shrink and expand so much with dryness and wet, and kept in their place better. In the 4-foot way, on the contrary, he kept the ballast down to the level of the top of the sleepers, so that the fastenings and condition of the sleepers could be seen, and the sand and fine particles of ballast were not then blown so much into the working parts of passing trains. Mr. Langley.

Mr. W. Stroudley considered the Author had done good service in drawing the attention of railway men to the risks incurred in using parallel axles in engines passing round sharp curves. The subject was at present only imperfectly understood. It would, however, have been better if the Author had been able to show the condition of the roads and the forms of the curves, as the wear of the wheel and rail were greatly dependent upon each other. If the curves on railways were so laid out that the clearance allowed between the wheels and the rails was taken up, by a slight divergence of the rail from a right line before entering upon the curve proper, the engine would pass round it without shock or oscillation. Curves were frequently made as parts of circles, and an engine, owing to the clearance between the wheels and the rails, would run forward from a straight line into a curve for a considerable distance before it would take the outer rail, and consequently would strike it with great force, causing oscillation and some risk of leaving the rails. He had found by experience that when a curve was so arranged that the wheel was brought gradually up to the outer or guiding rail, and the whole of the slack and elasticity of the bearings, frames, &c., were taken up, the train passed over it at high speed without oscillation or disturbance, provided the super-elevation of the outer rail was not too great. It had been the practice to elevate the outer rail much in excess of what was either good or safe. He believed that if the outer rail was kept somewhat above the level, say 2 inches, it was sufficient; he had known cases of as much as $7\frac{1}{2}$ inches super-elevation. With regard to the wheel-base of the engine, he thought, with the Author, that an extension of its length would make an engine safer to travel round a curve than with a short one, it being understood that the short wheel-base was such as would be represented by the bogie-wheels of the engine or carriage, or the distance between the leading and driving wheels as meant by the Author. The Author had stated that when the Mr. Stroudley.

Mr. Stroudley. inner driving-wheel flange was allowed to press against the inner rail, the trailing end of the engine acted as a lever, and forced the leading flange against the outer rail, with a greater amount of force than if the flange was taken off the driving wheel altogether. In practice Mr. Stroudley had cut away the flanges of the driving wheels, until they did not touch the rail. It would be a mistake to cut away the flange altogether from the driving wheels, because if the engine was de-railed it would be liable to turn round across the road, as the four-wheeled engines, and the engines made years ago without driving-wheel flanges, were found to do. With regard to the force exercised by the wheel on the inner side of the curve, urging forward that side of the engine, and so twisting it in a direction opposite to that of the curve, one thing had been lost sight of, namely, that the greater the amount of super-elevation of the outer rail, the greater the weight would be on the inner wheel; and the greater the amount of weight on the inner wheel, the greater the liability of the engine to leave the outer rail. That was his reason for recommending a moderate amount of elevation of the outer rail. He considered it safest for an engine to have a high centre of gravity, as in that case it would run round a curve with safety at great speed, because the centrifugal force threw over the engine, and put the greatest amount of weight on the outer wheels; in fact, the engine would run round a properly arranged curve at a high speed, with even less liability to leave the rails than at a low speed. He considered it an important matter, with a view to safety, to have the heaviest weight on the leading wheels. The case selected by the Author was somewhat extraordinary, the curve being of less radius than usual, and the engine much lighter, and it had at the trailing end a greater weight than at the leading end. It was not, therefore, a fair example of ordinary practice. He thought the form of flange, also, was well worth considering. For many years flanges were made with semicircular edges. He had found from experience that switches, supposed to be closed, were sometimes not quite close to the rail; and if the wheel had a semicircular edge, being pretty nearly square to the end of the partly-open switch, it would mount upon the point of the switch. If the flange was made with a more pointed form, as in the London, Brighton, and South Coast Railway Company's section, that would close the switch instead of mounting it. Since he had altered the form of flange, fewer engines had mounted the rails during shunting operations, and the same thing that was useful in shunting operations would give additional safety to an engine travelling at

Mr Stroudley. high speed. He thought the Paper would prove useful in drawing attention to a matter which had not been sufficiently considered. He believed that the highest speed could be obtained by the greatest amount of simplicity, and that every engine should be designed to suit the peculiar character of the work which it had to do. Where there were curves of 5-, 6-, or 7-chains radius to be worked regularly, special machines should be devised for them; but with curves of 20- or 30-chains radius, ordinary six-wheeled engines, with a rigid wheel-base of a moderate amount, say 16 feet, would suffice. He had known an engine run 110,000 miles with one set of wheels, with a rigid wheel-base of 15 feet 6 inches, without the wheels being removed to have the tires turned; the engine weighed 40 tons. When wheels on parallel axles would do work in that manner, he thought they could not cause much damage to the road, and there could not be much danger in employing such an engine.

Mr. Tomlinson. Mr. J. Tomlinson, Jun., said so few cases of derailment of engines had occurred within his thirty years' experience, that he thought there could not be much wrong after all. Theoretically, perhaps the Author was right, but in practice the difficulties and dangers indicated were not manifested, and therefore he considered the practice better than the theory, and that it would be safe to continue the existing method, and not to take the possibilities of danger too much to heart. If the dangers were to be weighed too carefully, the high-speed services of the country could not be carried on. It seemed to him that the engine, quoted by the Author from the Board of Trade Returns as having left the road, was of an exceptional character for these days, and such as could hardly be found now on a main line of railway, it being, as appeared by the distribution of weight, on a centre pivot, and ready at the slightest provocation to leave the rails, however good its working state might have been. The Metropolitan Railway, with which he had been connected for the last ten and a half years, was, he believed, one of the most difficult to work of any, so far as wheels and rails were concerned, owing to the frequency of curves of 10-chains radius often running into each other. But during the time he had been engaged upon it—and he believed since it was opened in 1863—no case of derailment of an engine had occurred which could be charged to the difficulties and dangers of which the Paper treated. In shunting, or in working through facing-points of some cross-over-road seldom used, this had occurred. The wear of wheels had been solely one of flanges, and scarcely, if at all, of the treads; but

Mr. Tomlinson. how this was to be overcome he could not say. It could not be solved by super-elevation, as, owing to the varying speeds the engines were by circumstances compelled to be worked at, no super-elevation, such as supplied by theory, would be available. It was of daily occurrence to have to stop the trains, or to run them slowly, when by rights the greatest speed should be attained; and thus, if stopped, great difficulty and loss of time would take place in starting again. He had therefore laid down on all curves of 10-chains radius and under, a check rail, and reduced the super-elevation to 2 or 2½ inches, which he considered safer than attempting to regulate the amount of super-elevation. In practice with a long wheel-based stock, when working at a low speed, the tendency of the trailing wheel was always to hug the low rail almost as much as the leading wheels did the high rail, and hence to mount the low rail. On the Metropolitan Railway, curves of 6-chains radius were daily passed over by hundreds of passenger-trains, with perfect safety, at speeds of 15 miles per hour. He agreed with Mr. Stroudley, that it was a good plan not to make the nose of the flanges too bluff; and also with Mr. Langley, that frequently an engine did, when the road was loose, actually form its own curve; he had often observed the bending of the rails in such cases. He also agreed that it was better to key the rail on the outside, as it made the road easier to work round, and he had adopted this plan when he changed the permanent way from the Vignoles section of rail to the bull-headed section.

Mr. Macnair. Mr. A. H. Macnair said that the Author had stated in Appendix II.: "A carriage with four, six, or more wheels on parallel axles, does not absolutely require flanges on any except the leading wheels, which being thus guided, the other wheels will follow them, and, if wide enough, will keep on the rails. Thus, when there is clearance enough, or the curve is easy, the whole of the flange friction comes on the outer leading wheel." That showed the great advantage there was in using a bogie, instead of leading wheels on a parallel axle under the engine, because it shortened the wheel-base and so reduced the side-sliding. It also showed the still greater advantage attending radial axles, getting rid of the side-sliding altogether, and leaving no sliding except backwards and forwards, which was inseparable from the case of two wheels of equal diameter running over rails of different lengths. This might be corrected, of course, by coning, but he agreed that coning was probably a mistake. It was recommended as a means of helping the vehicle round a curve, but clearly it was not of much assistance to the leading wheels, and in the case of the

other wheels it would be of use if they were coned in an opposite direction; that, however, was impossible, because the cant of the rails could only be in one direction. Coning would be useful if the road were all straight, and it would be useful on curves also, if the axles were radial; but with roads not straight, and with parallel axles, he thought the wheels would be better without coning. The Author's reasoning, of course, applied to all vehicles with parallel axles. Every vehicle in a train was more or less influenced. The leading end of each vehicle was running outwards, but the trailing end of the one in front of it was running inwards. No advantage, or, at any rate, the least possible advantage, was taken of this fact in the usual mode of coupling. He could not help thinking that if the couplings were crossed, so that the action of each vehicle might help the other, it would be to the advantage of both in getting round a curve. In regard to the super-elevation of the rail, he thought that was generally left as an entirely practical matter. If either rail seemed to be too much rubbed, the super-elevation had to be raised or lowered accordingly. The Author had stated in Appendix II. that if the flanges were removed from all the wheels, the carriage would run forward at a tangent to the curve. This was so far true; but if the carriage were at liberty it would also have a rotary motion round an axis of its own. On a straight road there was no such rotary motion; it was generated by the curve. Therefore the severest strain and the greatest danger were just when this rotary motion was generated all at once. That was at the commencement of the curve. There was no way to meet this danger but by a compound curve, so as to generate the rotary motion gradually. As Mr. Stroudley had remarked, a good deal depended on the nature of the curves. Professor Rankine had described a method of laying out curves for this purpose; it was to make the circular curve a little easier near the tangent by having it a little tighter at some other place. He was not aware that this method was generally adopted. He thought engineers required something that could be set out with the theodolite at one operation, like circular curves by the tangential method, for which he believed they were indebted to Professor Rankine. He had long thought that, as a circle was set out by equal angles, some method might be invented to set out the curves required by unequal angles. He had found no other method than that of making the necessary calculations, and had never had an opportunity in practice, but he believed that much good might be done in this way. Mr. Macnair.

Mr. W. W. Beaumont considered the members were indebted to Mr. Beaumont.

Mr. Beaumont. the Author for bringing forward an old subject in a new way and throwing a new light upon it. He was, he believed, the first to show in the way he had done the relation existing between the coefficient of adhesion and the pressure against the flanges of the leading wheels. In dealing with that question, and with the analogous one of the form of flanges, it had been usually assumed that velocity was a controlling element; and, in order to arrive at the force that had to be counteracted by the flanges, a maximum speed had been usually assumed. Wöhler had recently dwelt at some length upon the subject, and his calculations were based on that idea. The Author had been led chiefly to two points: first, that derailment was as likely at a low speed as at a high speed; and, secondly, that the danger of derailment did not necessarily increase in the inverse ratio of the radius of the curve. It appeared that the relation which he had shown to exist between adhesion and flange-friction was new to him, as thus stated: "In the case of the wheel most likely to mount the rail, namely the outer leading wheel, this side pressure, at low speeds, is principally caused by the resistance which the treads of the wheels oppose to the sliding motion which takes place in running round a curve;" an idea that he had developed in other parts of the Paper. Elsewhere he stated that "It will be assumed that, at moderate velocities, the flange-friction bears the same proportion to the pressure as does the adhesion of the tread, and that the two vary together when the state of the rails varies. This being so, with a double coefficient of friction the side pressure on the leading-wheel flange, required to make the other wheels slide, is doubled: at the same time the proportion which the flange's own adhesion bears to that side pressure is also doubled, so that the adhesion of the flange is fourfold." In applying that to the example he had given, he assumed a certain mean angle of flange surface; and in Fig. 4 he took that angle as 15°. Referring to the accident reported on by the Board of Trade officials, he arrived at the conclusion that it "might have been caused by the rails being in such a condition that the adhesion was 37 per cent. of the weight, assuming that it happened at a place where the gauge was sufficiently tight to allow the flange of the inner driving wheel to come into contact with the rail before that of the inner trailing wheel." Further on he increased the angle by 50 per cent. "The angle of the flange was just as likely to have been $22\frac{1}{2}°$ as 15°." And taking it at that, he said: "If the springs of the leading wheels had been very flexible, so that the flange would rise beyond the point of maximum stability without notice-

Mr. Beaumont.

ably increasing the load, the flange would have mounted the rail when the adhesion increased to 30 per cent." It was thus clear that an increase of the flange-angle, for instance, to the greater angle more commonly used, would materially decrease the coefficient of adhesion necessary to bring about derailment; and if that angle, instead of being 15° or 22½°, was say 30°, it might be easily seen that derailment ought to take place much more frequently than it did: supposing the other conditions assumed by the Author to be also true. There were several points which might be questioned tending to alter the conclusions to which the Author had come, but only in degree, not in principle. In the flanges on the diagrams, the angle was generally more than the Author had assumed; and in one case, on the Great Eastern Railway, the angle was very large and very much rounded between the tread and the flange, and on the outside of the flange; and as far as he knew that railway had not always been remarkable for derailment, though it was so during the year 1882. There were far more accidents from unexplained derailment in America than in England. That could hardly be said to be on account of long wheel-base, or because the permanent way was always so bad, since the accident occurred on some railways that had very good permanent ways. It appeared quite possible that the velocity at which trains were running had more effect on their derailment than might be supposed from the Paper, especially in the case of the long and heavy cars used in America, the inertia-motion of which might push the bogies off the line when entering curves. That was to say that the heavy cars refused to change their course as rapidly as the light short wheel-based bogies. As to the question of coning, it was rather doubtful whether that also did not come into play in preventing slipping, thus making a discrepancy between the Author's conclusions as to the number of derailments there ought to be and the number there actually were. No doubt there was a certain amount of agreement between the different wheels and axles of an engine as they went round a curve, managing the business amongst themselves. It was not altogether a slipping forward of the outer wheels, or a slipping backward of the inner ones, but a little of each, and that might to a considerable extent upset the Author's calculations. As to the question of the best size for leading wheels, different locomotive engineers had different opinions, the larger wheel being held to be more likely to mount the rail under some conditions than the smaller wheel with the same form of flange. It was quite evident that the experience of Mr. Langley and of the

Mr. Beaumont. Author pointed to the necessity of using radial axles whenever it was possible. Perhaps a system had not yet been brought out suitable for engines, but no doubt there were very good systems for vehicles. It was certainly curious that vehicles should still be used with wheels fixed on parallel axles to run round small curves.

Mr. Woods. Mr. E. WOODS, Vice-President, thought that practice was a safer guide than theory in matters of that kind. He should be sorry to base the design of an engine simply upon mathematical considerations as to the amount of adhesion between the wheel and the rail, or between the flange and the rail. He agreed with Mr. Stroudley that the construction of a railway had a good deal to do with the facility with which engines could pass round curves, but he thought the construction of the engine itself, in the sense of specially adapting it to traverse curves, was also a matter of importance. The difficulty was felt very early on the American lines, many of which were laid not only with sharp curves, but, like a contractor's railway, the rails not laid on chairs, but simply flat-footed rails spiked on to the sleepers, and at first hardly fish-jointed; consequently where curves occurred the tendency of the carriages and engine to go off the line was greater than it would be on the better-constructed railways of this country. The difficulty was remedied in America by the introduction of the bogie-truck. Almost all the early American engines rested on a four-wheeled bogie-truck at the leading end. At first the trucks were pivoted on a fixed centre; latterly they had a transverse motion, as in Adams's bogie-truck. The effect was to apply a steady lateral pressure to the leading end of the engine, and to cause the engine to traverse the curves in an easy and smooth manner. The introduction of that truck enabled the wheel-base to be considerably reduced, because even for a four-wheeled engine the flanges of the leading driving-wheels could be dispensed with, and so the wheel-base be reduced from 10, or 12, or 14 feet to not more than from 6 to 8 feet. He had for many years worked with engines of that kind round curves of 5- and even 4-chains radius. Most of the lines on the south coast of America were laid on that principle, and were worked with engines of the class he had mentioned; and he was not aware that any accident had happened from derailment except in cases of very steep inclines, where a train had got loose and was running at a speed of 50 or 60 miles an hour. The ordinary speed was from 25 to 30 miles an hour. The subject was an interesting one, and he hoped that more

attention would be given to it than had hitherto been bestowed on it. Mr. Woods.

Mr. H. S. Ridings said that in the case of lines with sharp curves combined with steep gradients, as on the west coast of South America, several elements of danger had not been touched upon. Sometimes, when there was a tendency, the rails being wet, for the train to break loose, the brakesmen skidded the wheels, in which case the engine or wagon would mount the rail much more readily than before. He well remembered one accident of that kind of which the results were very deplorable. The locomotive was one of Fairlie's double-bogie engines, which if properly treated would have easily gone round the curves. The train was a long one, and it was too heavy, the rails were wet, and it was night time. The brakesman was, as usual, on the opposite side to the engine-driver, and was not under his control. The driver, perceiving that he could not hold the train tried to reverse the engine, while the brakesman was putting his brake hard on and skidding the wheels. The engine went off against the side of a cliff, the boiler burst, and there was a great loss of life. Reversing an engine was a source of danger, because the wheels would mount the rails more readily. Sharp curves on lines such as those to which he had referred, where there were reverse curves of 350-feet radius, on gradients of 1 in 25, were sometimes a source of safety. Occasionally, owing to the small number of engines, it was found necessary to bring down a very long train, and the effect of the sharp curves had been to retard it and prevent it from breaking loose. That, he believed, had often prevented terrible accidents. On a straight road, or one with easy curves, such long trains could not have been brought down, because they would have inevitably broken loose. Mr. Ridings.

Mr. E. A. Cowper said that some years ago he made some experiments as to the adhesion of dry wheels upon dry rails. It often ran up to 25 per cent., and, in a few cases, to 33 per cent., of the weight of the engine. He had tried it with a pair of 7-feet wheels, and he dragged them on the line without rolling, so that he was certain that he had got the exact result. When an engine was running round a sharp curve, no doubt there was considerable pressure against the outside rail; but notwithstanding this, if the engine and the line were in good order, no accident would occur; but if the flange were worn square, it might catch and ride on a bad or projecting joint in the rails on a curve. A number of accidents happened, through some fault in the rails, in going round curves. He had been round very sharp curves, at Mr. Cowper.

Mr. Cowper. very high speed, without any evil consequences, and without any very bad motion; but if the speed was high, the line bad, and the motion at all irregular, there was, no doubt, a good deal of danger.

Mr. Mackenzie. Mr. JOHN MACKENZIE, in reply, observed that he did not agree with the remark of Mr. Owen, that "theoretically, according to the Paper, every six-wheeled engine ought to run off the rails," as it was probably very seldom that adhesion was as high as 37 per cent.; and, though liable to happen at any time, it might not happen during the lifetime of an engine that this high rate of adhesion should exist along with the other circumstances necessary to cause a well-proportioned engine to leave the rails. Indeed, the Paper was open to criticism quite the reverse of that of Mr. Owen. It might have been urged, that the Paper was an attempt to treat in a loose and popular way a subject more fit for a strict mathematical and physical investigation; and that, even allowing it all to be correct, it treated of a danger which had always been recognised, and which was not very great unless under circumstances which could hardly occur, and with proportions which nobody would adopt; and such criticism could not have been easily met. Mr. Owen went on to say the fact remained that engines did not run off the rails: but temporary immunity from accident was no certain proof of the absence of danger: for instance, the Tay Bridge had been shown to have been unsafe from the beginning, but it stood unsuspected for some time, and, but for one unfortunate gale, it might have been standing now, and still have been pointed to as an example of boldness of design and a monument of engineering genius. Mr. Browne said: "It was obvious that if the gauge differed so much within so short a distance, that in itself constituted a considerable obstacle tending to throw the engine sideways; and it was a cause nearly independent of the speed at which the engine was going, accounting therefore for cases of derailment at low speed," &c. Now when a wheel, travelling slowly on a horizontal plane, came into contact with an obstacle, it must either stop, or rise over the obstacle, or be turned aside by it; the circumstances determining the conduct of the wheel being the angles which the surfaces at the point of contact formed with the plane of the wheel, and with the horizontal plane, as well as the proportion of friction to pressure, and the direction of the force, or resultant of forces, by which the wheel was pressed against the obstacle. The flange of an engine-wheel in this acted much as any ordinary wheel would do, the side of the rail constituting an obstacle lying at a

very obtuse angle to the plane of the wheel; so that generally the wheel was turned aside, but in exceptional cases it rose over the obstacle, and in the absence of any defect in the rail it was friction alone which gave the flange the hold on the rail which enabled it to rise. Referring to the sections of tires exhibited, Mr. Browne "supposed that every wheel running on an English railway was coned." It should be explained that the sections alluded to all showed tires of leading wheels of engines, and that the Great Eastern and the London, Brighton, and South Coast Railway Companies made the tires of driving wheels cylindrical on the tread, and with very thin flanges. Probably the same might be the practice of some other companies. Mr. Mackenzie.

A remarkable case had been mentioned by Mr. Grover, in which the wheels of a locomotive kept on the rails when keyed on the axles, but ran off when made loose. A possible explanation might be that the side pressure on the flange was less than the load on both wheels, but greater than the load on its own wheel. Thus, when keyed on, both wheels would revolve at the velocity due to the treads, or to one of them, and the flange at its point of contact with the rail would move at a higher velocity, sliding backwards on the rail, so that the friction between them would be the friction of a skidded wheel, and consequently less in proportion to the pressure than the adhesion of the treads. When the flanges were loose, the pressure on the flange being, by hypothesis, greater than that of the one tread, the wheel would revolve at the velocity due to the point of contact of the flange, and the friction of the flange would change into adhesion, while that of the tread would be the smaller friction of a skidded wheel. In short, with fixed wheels the flange friction was the friction of motion, while with loose wheels it was the friction of rest. From this it would appear that, although the tractional resistance and the wear would be greater, the danger would be less when there were two points of contact between the wheel and the rail, than when there is only one (Appendix IV.). In the latter case, when the outer leading wheel moved towards the rail on a curve, there must be one position in which the velocity of the outer wheel at the point of contact would be exactly that due to the tread of the inner wheel, so that neither wheel would slide, adhesion would be complete, and this adhesion would continue in the case of the outer wheel, and when its flange rose over the rail it would, by its greater pressure and adhesion, cause the tread of the inner wheel to slide. This, however, would not be the case if the leading wheels were coupled to the driving wheels. The above indicated that, when there was one point of

Mr. Mackenzie. contact and the leading wheels were not coupled, adhesion of the flange might take place, not only at low speeds, but also at higher velocities. On the other hand, assuming that in Mr. Grover's experiments there were two points of contact, these experiments seemed to show that, in proportion to pressure, flange friction was less than tread friction, not only at high speeds, but also when moving slowly, as no doubt was the case with the wheels in question. This being so, the mode of calculating the example quoted from the returns of railway accidents, would apply solely to cases where there was only one point of contact between the wheel and the rail. Where there were two points of contact, flange adhesion would be much less likely to occur; but if, by any slight inequality of the rail, or by oscillation, adhesion of the flange once set in, it would continue, unless when the leading wheels were coupled.

In quoting the words "within the limits of practice," Mr. Grover certainly did not keep within those limits when he asked the Meeting to "consider the wheel-base as equal to twice the radius." When, however, after stating the extreme limits, he went on to say that "between those limits there was, no doubt, a proportion beyond which it was evident that, with an increased wheel-base, the danger of running off the curve was increased," he was quite in accordance with the Paper, although there was a difference of opinion as to what that proportion was, and Mr. Grover's view of the matter was not altogether upheld by subsequent speakers. Mr. Grover further said that, when the tractional resistance was increased, "it was absurd to say that the danger was not at the same time increased." But here he was wrong, as the tractional resistance depended on the distance which the wheels slid in travelling a certain length along the rails, as well as on the weights on the wheels; while the danger depended principally upon the proportion of weight which held down the leading wheel, and the leverage with which this wheel acted on the others. Thus the tractional resistance and the danger did not depend upon the same circumstances; and although they might often increase and diminish together, they did not always, nor necessarily, do so. A small tractional resistance in going round a curve was not invariably a proof of safety from running off the rails. It might, on the contrary, be a symptom of extreme danger. The best possible proof of this was the case quoted by Mr. Grover, where wheels were made loose on the axles, no doubt with the express intention of lessening the tractional resistance, with the result that they ran off the rails. A carriage with an extremely short wheel-base would

run very easily round a curve; but it would be in considerable danger of running off the rails owing to the short leverage with which the outer leading flange resisted the tendency of the inner wheels to outrun the outer ones, and twist round so as to face the outer rail. Mr. Grover remarked that "the reason was that those long carriages, many of them with 22-feet wheel-base, going round curves of 300 or 400-feet radius, had a great tendency to mount the outer rail. The wheel ground the outer rail until it got hold of something, and the check-rail, being a little slack, allowed it to do so, and off it went." This last sentence might be taken as a complete brief abstract of the Paper; the only difference of opinion probably being as to what the "something" was. In the Paper it was supposed to be the side of the rail, the adhesion being sufficient to allow the wheel to get hold of it, the precise spot being probably determined by some slight indentation or irregularity in either the rail or the wheel. If Mr. Grover meant by "something" a loose or imperfect joint, he was not at variance with anything stated or implied in the Paper, unless perhaps he might demur to the extreme smallness of the defect which, according to the Paper, would, in addition to the adhesion, be sufficient to make the flange mount the rail under certain circumstances. Mr. Grover's description of the accident to a tramcar was, he thought, hardly to the point; but it might serve as an excuse for saying that these vehicles afforded a strong confirmation of the opinion expressed in the Paper, namely, that only a sufficient side-pressure, and that not extremely great, was required to cause flanged wheels to mount the rail. When two trams met on a single line, the driver of one turned his horses to one side, so as to pull at an angle, and the wheels left the rails, although in this case there were two leading-wheel flanges to mount out of their grooves. As settling a somewhat difficult point, particular notice should be taken of the statement of Mr. Langley, that an engine he described "flattened the curve in its progress," confirmed as these words were by Mr. Tomlinson when he said that he agreed "that frequently an engine did, when the road was loose, actually form its own curve." Thus the springing of the rails would maintain the tightness through some little range, probably sometimes great enough to enable the flange to climb to the top of the rail. This springing of the rails was evidence of considerable side pressure. Mr. Mackenzie.

The remarks of Mr. Stroudley were most instructive. As regarded the flanges on driving-wheels, as long as they did not touch the rail they could do no harm; but it seemed questionable whether it was advisable to contribute, even in the most remote

Mr. Mackenzie. degree, to the risk of an accident on a very sharp curve for the sake of lessening its effects. Prevention was better than cure. The remark as to the safety of a high centre of gravity was most important where high speeds were concerned. It was a point omitted in the Paper—and indeed, at the low speeds treated of, it hardly came into play. In the case quoted in the Paper, the centrifugal force was more than balanced by the cant, so that raising the centre of gravity would have lessened, instead of increased, the weight on the outer wheels.

It had been said by Mr. Beaumont that "It was not altogether a slipping forward of the outer wheels, or a slipping backward of the inner ones, but a little of each;" and Mr. Cowper had considered the case of a carriage revolving on the rails about its centre. Now this being thought a very doubtful point, some experiments had been made, and it was found that a model would not revolve about any imaginary centre, however the weights were arranged, but that it always revolved about some one actual point of contact, all the others sliding. When it could not move from one position to another by revolving about one centre, it first revolved round one point of contact, and then round another, until, by a succession of small movements, it had taken up its new position. From the extremely rough way in which the experiments were made, no great reliance was placed upon them; but they seemed sufficient to justify the views expressed in the Paper. This point did not greatly affect the result. It was not meant by the above that, when not coupled, all the outer wheels slid forwards, or all inner ones backwards; probably it was often otherwise. Mr. Beaumont further said that "It appeared quite possible that the velocity at which trains were running had more effect on their derailment than might be supposed from the Paper, especially in the case of the long and heavy cars used in America, the inertia-motion of which might push the bogies off the line when entering curves." In this case Mr. Beaumont was probably correct. The remarks in the Paper applied only to six-wheeled engines or vehicles. In a four-wheeled carriage, the outer leading-wheel flange had to resist half the unbalanced centrifugal force; so that such a carriage, though less likely than a six-wheeled one to leave the rails at slow speeds, might be more dangerous when the velocity was increased. A bogie in this resembled any other four-wheeled carriage with a very short wheel-base, and indeed was more dangerous, being pushed along by a pin some distance behind the front axle, so that any slight deviation had a tendency to increase. Indeed a long carriage on two bogies was a most insecure-looking

Mr. Mackenzie.

contrivance, whose character would probably upon investigation be found to correspond with its appearance. In the "Engineer" of the 4th of May, 1883, there appeared a list of accidents on American railways during February, numbering in all one hundred and eighty-four, of which one hundred and thirteen were from "derailment," and thirty-six of the hundred and thirteen were "unexplained," being the only unexplained accidents on the list. Although not claimed by him, it was due to Mr. Macnair to state that some part of the Paper had been suggested by remarks made by him in a discussion on a Paper on "Train-Resistance on Railways."[1]

With regard to a few general observations as to the theoretical and mathematical nature of the Paper, it could only be replied that it was inevitable that this should be the case if the subject was to be treated at all. An unwillingness to adopt novelties whose safety or economy were unproved, was a conservatism of the most valuable kind; but an opposition to an inquiry into a cause of accidents, merely because it was theoretical, was as much an element of danger as was resistance on railway curves.

Correspondence.

Mr. Fidler.

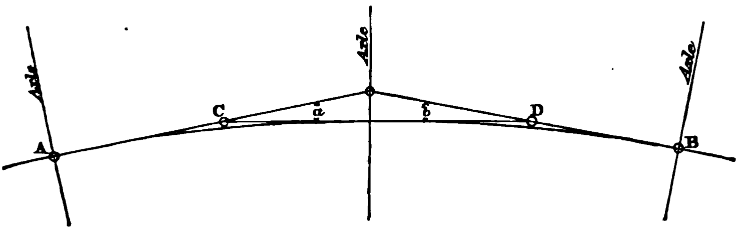
Mr. T. C. Fidler remarked that the numerous sources which contributed to the increased resistance of railway vehicles upon sharp curves had been frequently investigated, and among these there could be no doubt that the most important were to be found in the conditions which produced the skidding motion of the wheels, and by which the leading and trailing wheels were continually dragged across the rail in a diagonal direction, as shown in Fig. 1. Neglecting the effect of any spreading of the gauge, this diagonal skidding motion might be resolved into two components, due respectively to two distinct causes, namely, first a transverse slip in the direction of the axle, due to the fixed parallelism of the axles, and proportional to the length of wheel-base; and, secondly, a longitudinal slip at right angles to the above, due to the fixity of the wheels upon the axle, and proportional to the width of gauge. These two component motions were indicated by the Author, but their relative values, which were in the ratio of length of wheel-base to width of gauge, did

[1] Minutes of Proceedings Inst. C.E., vol. xxxi., p. 403.

Mr. Fidler. not appear to be clearly shown. The first, generally much the greater of the two, would be remedied by radiating the axles as normals to the curve; the second by allowing the wheels to run loose upon the axle. The latter expedient was, no doubt, open to serious practical objections, probably of sufficient weight to preclude its adoption for railway purposes, while its application would, after all, only remedy a small part of the evil; but Mr. Fidler had long been of opinion that the automatic radiation of the axles afforded a perfectly feasible means of curing the chief part of the evil, and if carried out with simple constructive arrangements, and with fixed wheels, would be open to no such objections as those above referred to. It was a matter of common observation that a wheel would only roll along a path at right angles with its axis of revolution, and that it could not be constrained to follow any other line, except by dragging it across the path of its natural rolling progression; and the necessity of fixing the axles at right angles to the line of rails had always been practically recognised, although generally only imperfectly complied with. In an ordinary four-wheeled truck, the axles were fixed at right angles to a chord whose length was equal to the wheel-base, or rather they were fixed at right angles to the centre line of the truck, which approximately occupied the position of a chord upon the curve, subject to certain oscillations due to the play of the wheel-flanges between the rails. By reducing the length of wheel-base, the obliquity of the chord to the normal was of course diminished, but at the same time the angular measure of this oscillation was increased; and it might be shown that the smallest obliquity of the axle was obtained when the length of wheel-base $= \sqrt{2 \text{ R } c}$, in which R was the radius of curve, and c the clearance of the flanges between the rails. For example, if $\text{R} = 10$ chains, and $c = \frac{3}{4}$ inch, it would be found that the best length of wheel-base was about 9 feet, and that any shorter length would be attended with an increased obliquity of the axle. For this reason the American bogie could only offer a partial remedy for the evil. The automatic radiation of the axles was first accomplished by Messrs. Wilkin and Clark, by mechanism which connected and controlled the motion of the axle-boxes of three independent axles. In 1868 Mr. Fidler had proposed to mount each pair of wheels in an independent bogie, and to couple three of such bogies together in such a manner that the centre line of each should be automatically adjusted in the position of a tangent to the curve, as shown in Fig. 5. If the three axles were supposed to be spaced radially at equal distances, the tangents would be of

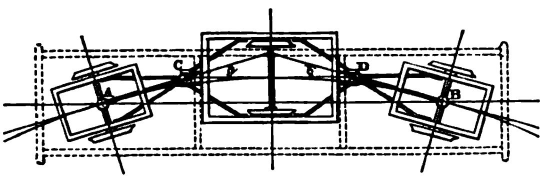
equal lengths, and the angles *a* and *b* would always be equal, whatever the radius of the curve; and it was evident that, in order to ensure the automatic radiation of the axles upon any curve of Mr. Fidler.

FIG. 5.



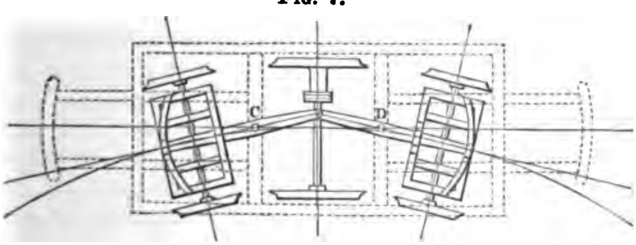
finite or infinite radius, it was only necessary to couple the bogies together at the intersection of the tangents, or at the points C and

FIG. 6.



D, and to connect them in such manner that the angular motions *a* and *b* should take place in the same direction, and should be

FIG. 7.



equal in extent. This was effected by arrangements which varied according to the mode in which the main body of the vehicle was carried upon the three bogies. The three principal methods of construction included in Mr. Fidler's system[1] were illustrated in

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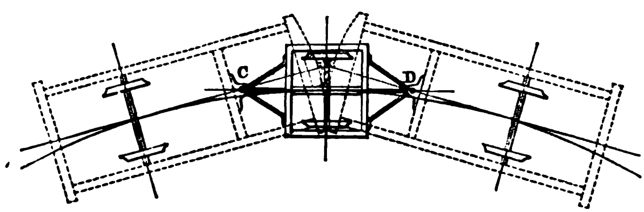
[1] Specifications of patents for inventions, Nos. 2,399 and 3,825 of 1868, now expired.

Mr. Fidler. Figs. 6, 7, and 8. In Fig. 6 the main frame was independent of all the bogies, and was centred upon the two end bogies at A and B, while the middle bogie traversed under the main frame. In this case the middle bogie was made to preserve a parallel position during its transverse motion, either by guides fixed under the main frame, as in the first tramway carriages constructed upon this principle, about fourteen years ago, or by means of swinging suspending links, similar to those employed in the car bogies of American railway carriages. In Fig. 7 the main frame formed a continuation of the middle bogie of the system, or, in other words, the middle pair of wheels was mounted in the main frame in the ordinary way, while the two end bogies were centred at C and D, corresponding to the points C and D in Fig. 5. In this case the equality of angular motion was secured (as it might be in either of the three cases) by coupling together the meeting ends of the longitudinal arms which formed a prolongation of the centre lines

Fig. 8.



of the bogies, as shown in the figure. Again, in Fig. 8 the end bogies were treated as forming the main frames of a pair of twin-carriages, their meeting ends being coupled together, while the middle bogie was centred at both its ends at the points C and D, which were situated as before. In each of the three cases the principle was evidently the same, and the respective centres of motion and centre lines of the bogies or frames were referable in the same way to the lines of the skeleton diagram, Fig. 5. The requisite amount of longitudinal play was provided for at the couplings. By this system it was evident that the obliquity of the axle was entirely removed, except that portion of it produced by the lateral play of the wheel-flanges. With a short wheel-base this lateral play might be attended with some considerable obliquity of axle, but as the system offered the means of employing a long wheel-base, even in carriages which had to traverse sharp curves, this source of error might also be reduced to a minimum. When the carriage was standing partly upon a curve, and partly

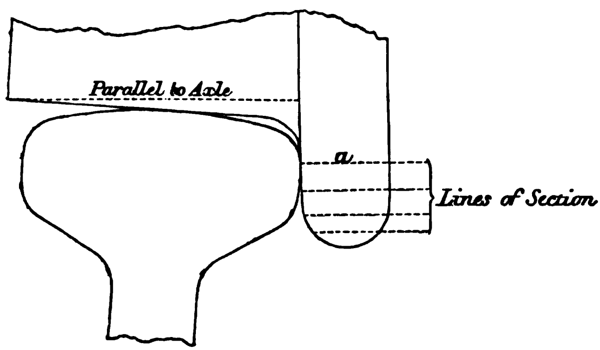
upon a straight line, the radiation of the axles was not accurately at right angles to the rails, but in lines converging to the centre of that circular arc which might be drawn through the three points occupied by the three wheels on either rail; the system, in fact, performed a mechanical solution of the 1st proposition of the 3rd Book of Euclid, and found automatically the centre of the circle in which three points were given. During the recent construction of the cars for the Japanese tramways, which were built under the superintendence of Mr. J. Brunton and himself, some experiments were made to ascertain the tractive resistance of this six-wheeled radiating system upon a sharp curve, as compared with the resistance of an ordinary four-wheeled car. It was specified that all the cars should be capable of running easily upon a curve of 25-feet radius. Rails were accordingly laid to this curvature in the workshop, and four cars of different construction were tried, and their tractive resistances measured by a dynamometer. The first was an ordinary four-wheeled car, with wheels fixed upon the axles, the wheel-base being 4 feet 6 inches, and the gauge 4 feet 6 inches. The second was a similar car, with wheels loose upon the axles, *i.e.*, one wheel loose upon each axle. The third was a six-wheeled car, with a wheel-base of 7 feet, with radiating axles as shown in Fig. 6, and with loose wheels. The fourth was also a six-wheeled car, but constructed as shown in Fig. 7, and also with loose wheels. The bearings were new and stiff, and the resistance of all the cars upon the straight line was nearly 40 lbs. per ton. Upon the curve of 25-feet radius, the additional curve resistance was:— Mr. Fidler.

	Lbs. per ton.
No. 1. Four-wheeled car, fixed wheels	72
„ 2. „ „ loose wheels	44
„ 3. Six-wheeled car, radiating axles	4
„ 4. „ „ „ „	3

As the six-wheeled cars had not only radial axles, but also loose wheels, it might be expected that no additional resistance would be experienced upon the curve; the small resistance of 3 or 4 lbs. per ton observed to take place, in excess of the straight line resistance, was probably to be attributed to the friction of the loose wheels in their differential revolution upon the axle. In actual working upon the tramways, it had been reported from Japan that the six-wheeled cars ran with ease and safety over the sharpest curves of the line, where the four-wheeled cars were frequently running off the line.

Mr. Phipps. Mr. G. H. Phipps, while concurring generally with the Author in his method of examining the grinding resistance of the wheels of six-wheeled coupled engines on sharp curves, was convinced that the coefficient of friction taken at 37 per cent. on all the six wheels, was far too high. Mr. Phipps was also of opinion that, even with the above coefficient, the tendency to lift the outer leading wheel, so as to cause the flange to mount the rail, was greatly overrated. In order to determine the tendency of the wheel to rise, it was only needful to know, first, the lateral pressure of the flange against the rail; and secondly, the ratio of sine to radius of the angle made by the rail with the tangent to the flange at the point where the friction was applied. The pressure was to be obtained (Fig. 13) by dividing the sum of the horizontal moments of the adhesion of the wheels to the rail, derived from the weights

Fig. 9.



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given by the Author, taken into their respective distances from A, the centre of the inside driving wheel, and this, divided by the distances of the point of application of the lateral force on the outside leading wheel from the point A. The result was, with 37 per cent. of adhesion, $\frac{53 \cdot 40}{7 \cdot 16}$, or 7·45 tons, requisite side-pressure to cause all the wheels to slide. The angle was to be obtained by a reference to Figs. 9, 10, 11 and 12, where Figs. 9, 10 and 11 were to show the horizontal section of the wheel flange at the level of the rail, producing Fig. 11, whence showing the rail at an angle of 2° (which would not be exceeded on a 10-chain curve, allowing also for taking up slackness of gauge), with the curve placed the tangential point C, although rather less was

however taken at 6 inches from the centre of the wheel. Referring next to the elevation, Fig. 12 (which was drawn with a radius of 2 feet), B C showed the above 6 inches. Then the direction of the lifting force P would be C D, forming the Mr. Phipps.

FIG. 10.

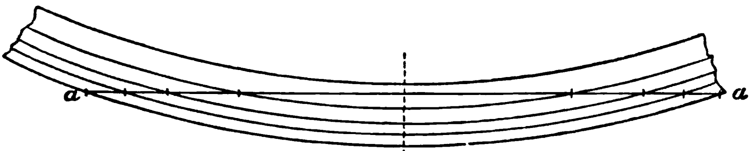
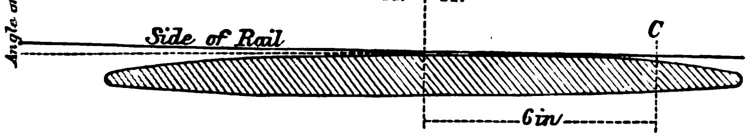


FIG. 11.



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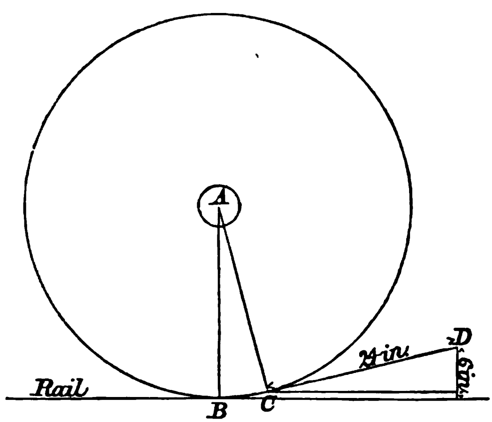
same angle with the rail as B A C, and giving a vertical force of one-quarter that on C D. Now, 7·45 tons had been shown to

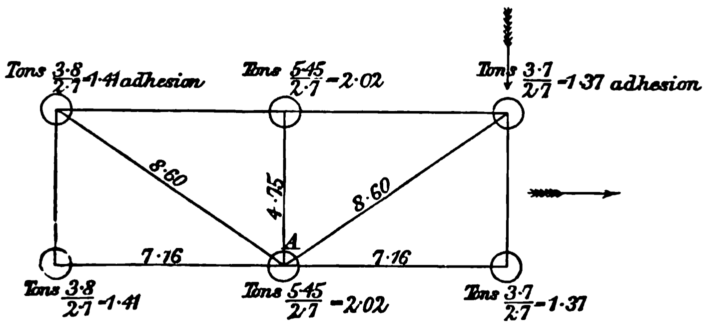
FIG. 12.



be the lateral pressure against the point C, Fig. 12, of the flange, which, reduced for adhesion, $\frac{7 \cdot 45}{2 \cdot 7}$ was equal to 2·74 tons, which again applied in the direction C D, reduced the vertical lift to $\frac{2 \cdot 74}{4} = 0 \cdot 68$ ton, where the insistent weight on the wheel was

Mr. Phipps. 3·7 tons. Having stated above his opinion that the coefficient for friction of 37 per cent. was too great, he would further observe that it was founded upon exceptional experiments by Captain Douglas Galton, when sand was strewn on a still day in front of the driving wheels; but, even if this were so, it certainly could not apply to all the other wheels of the

FIG. 13.



engine. Mr. Phipps would suggest whether six-wheeled coupled engines were not more likely to mount the rail from oscillation of the engines on a vertical plane about the driving wheel axle as a centre, when the road was out of order. The absence of coincidence of the pulling link from the line of pull of the engine wheels, no doubt, promoting the oscillation just referred to.

Mr. Whitley. Mr. H. M. WHITLEY observed that the Author had investigated at length the theoretical forces tending to cause a six-wheeled coupled engine to leave the rails while running round a sharp curve; but, when the enormous traffic of the British Isles was taken into account, it was surprising how few accidents occurred which were solely due to passing at high speed round curves; and this was clearly shown by the Reports of the Inspecting Officers of the Board of Trade. Excluding station-yards and junctions, where the points or crossings were generally the cause, and cases in which defective permanent way and an unsuitable engine led to the accident, only sixteen cases had been reported on in the past twenty-two years, and in several of these, no doubt, the road or engine was partly in fault. In order to ascertain from practice the minimum limit of the radius of a curve, consistent with ordinary railway working, he had extracted from the before-mentioned returns the accidents due to curves for the years between 1860 and 1881, as shown in the annexed Tables. With respect, first, to Table I., p. 56, for the broad-gauge lines, all the occasions on which

engines with such a long wheel-base as 18 feet 3 inches, have left the road, had been on curves of and under 15-chains radius, and without a check-rail, the speed being in one case 30 miles per hour. For fast running, 20-chain curves were safely worked, there being many of this radius on the Cornwall Railway, and the "Flying Dutchman" was taken between Plymouth and Truro by a broad-gauge, all-coupled, six-wheeled, tank, goods engine, weighing about 38 tons, with a wheel-base of 15 feet 4 inches, the speed on portions of the line being about 45 miles per hour. A still sharper curve of 17 chains occurred at Cornwood, on the South Devon Railway. This was run over at 30 to 40 miles per hour, a speed which approached the maximum consistent with safety for fast working, especially with the old six-wheeled coaches. Three or four cases of running off the line had taken place on this curve, but now, with bogie-carriages, it was taken easily and safely. For the narrow gauge lines (Table II., p. 56) hardly any accident happened on curves over 10-chains radius, except where the road or engine was mainly in fault. The Table further showed the danger of a tight road on a curve, and the increased safety that heavier permanent way and check-rails had secured; but even a check-rail and bogie engine would not entail safety in such cases as Nos. 1 and 2, and it was to be feared that continuous brakes sometimes induced drivers to approach junction curves at a higher speed than was advisable; and the practice of inserting such sharp curves in station-yards was questionable, especially bearing in mind the present tendency towards increased wheel-base for coaching stock. The deduction from the Tables was that, at the average speed at which British railways were worked, no accidents were due to curves exceeding about 17-chains radius with engine and road in good order; and that the general practice of taking 40 chains as the minimum radius for fast express traffic was absolutely safe; whilst for curves under 15-chains radius, which at times were run over at high speed, a guard rail was essential to secure safety. He could not agree with the Author that flanges on the driving wheels were worse than useless. The old engine stock of the West Cornwall Railway, consisting of six-wheel engines, was so designed, in order to adapt them for the numerous sharp curves on the line, and they were notorious for leaving the road; one engine, the "St. Ives," having got off twice in one day, and four times in three weeks; and when the leading wheels mounted, the engines swung round, and went up the side of the cutting or down the bank at once, having no flanges on their centre wheels to keep them straight.

Mr. Whitley.

Mr. Whitley.

TABLE I.—ACCIDENTS on CURVES. BROAD GAUGE, 1860 to 1881.

No.	Name of Railway.	Date.	Radius of Curve.	Gauge.	Cant.	Wheel-Base.		Speed per Hour.	Cause of Accident.
			Chains.	Inch.	Inches.	Ft.	Ins.	Miles.	
1	Great Western .	29/5/72	8·6	$\frac{1}{2}$ wide	6	15	0	10	Deficiency of weight on leading wheel of engine.
2	" " .	25/6/73	8·6	$\frac{1}{4}$ "	6	19	0	5	Too long wheel-base. Engine mounted.
3	" " .	1/6/67	13·0	$\frac{3}{4}$ "	$2\frac{1}{2}$	14	8	..	Improperly balanced engine.
4	Bristol and Exeter	21/7/63	14·0	$\frac{3}{8}$ "	6	18	3	10 to 20	Too fast with long wheel-base round curve.
5	Great Western .	24/8/66	15·0	$\frac{9}{16}$ "	$5\frac{1}{2}$	18	3	30	" " " "
6	South Devon . .	25/11/65	17·0	$\frac{1}{2}$ "	$5\frac{1}{2}$	15	4	30	Goods engine, too fast round curve.
7	" " . .	19/10/75	18·0	$\frac{1}{2}$ "	$6\frac{1}{2}$	18	3	40	Brake van off rails, road not in good order.
8	" " . .	2/6/74	20·0	$\frac{1}{2}$ "	$7\frac{1}{2}$	15	4	30	Goods engine mounted rails.
9	" " . .	19/6/74	23·0	$\frac{3}{8}$ "	$5\frac{1}{2}$	..		35	Leading wheels of coach left rails from some fault.
10	Cornwall . . .	25/11/68	28·0	$\frac{3}{8}$ tight	$3\frac{1}{8}$	..		30	Line tight to gauge.

TABLE II.—ACCIDENTS on CURVES. NARROW GAUGE, 1860 to 1881.

No.	Name of Railway.	Date.	Radius of Curve.	Gauge.	Cant.	Wheel-Base.		Speed per Hour.	Cause of Accident.
			Chains.	Inch.	Inches.	Ft.	Ins.	Miles.	
1	Cheshire Lines .	2/8/80	4·0	..	2	16	6	30	Too fast round curve into station, check rail.
2	Great Northern .	23/6/78	6·3	True	Nil	22	6	15 to 20	" " bogie engine, check rail.
3	Great Western .	22/6/72	8·6	$\frac{3}{8}$ wide	5	15	8	8	Engine mounted rail.
4	Macclesfield . .	11/3/79	9·5	$\frac{9}{16}$ "	..	14	4	15	
5	Caledonian . .	8/7/76	9·5	True	$5\frac{1}{2}$	13	$0\frac{1}{2}$	20	Too fast round curve.
6	Midland . . .	13/9/62	11·0	..	Nil	15	6	20 to 30	" " goods engine.
7	South Yorkshire .	21/10/62	12·0	$\frac{1}{16}$ tight	4	14	$5\frac{1}{2}$	20	" " unfinished road.
8	Great Northern .	7/12/77	17·0	$\frac{1}{16}$ "	Nil	15	2	20	" " engine mounted at junction.
9	North Eastern .	25/3/77	$17·0\frac{1}{2}$	$\frac{1}{4}$ "	$1\frac{1}{4}$	16	1	25	Defective joint.

Mr. Mackenzie.

Mr. Mackenzie, in reply to the Correspondence, observed that in a question of danger nothing less than the highest observed amount could be taken as the maximum. Of course 37 per cent. of friction, which Mr. Phipps thought far too high, was exceptional; but it was in exceptional cases that accidents occurred. Mr. Phipps was also of opinion that even with this friction the tendency to lift the wheel was overrated; but his estimate of the side pressure, and the consequent adhesion to the side of the rail when vertical, did not differ greatly from that stated in the Paper. If the cross-section, Fig. 9, had been taken through the point of contact C, Fig. 11, it would have been found that the surfaces at that point were considerably inclined, thus increasing the weight which the adhesion would sustain. It was not easy to see why Mr. Phipps divided the adhesion by 4. The adhesion resulting from the side-pressure did not lift the wheel, it only prevented it from falling. The adhesion only held on while the steam in the cylinders did the work. Referring to Fig. 12, when this adhesion was sufficient to sustain the weight, the wheel ran up the line C D, as if working in a rack. It had been remarked by Mr. Whitley that accidents were few when those arising from certain causes were excluded, and among others he excluded the accidents caused by unsuitable engines. Now it was precisely this class of accidents that formed the subject of the Paper; and that these accidents were not very rare might be seen by the Inspector's reports, and by the concluding paragraph of Mr. Whitley's remarks.

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1 May, 1883.

JAMES BRUNLEES, F.R.S.E., President, in the Chair.

The following Associate Members have been transferred to the Class of

Members.

Henry Adams.
William Boulton.
Charles Toler Burke.
William Crabtree.
Joseph Francis.
"Rai Bahadoor" Kunhya Lall.
James Campbell Ledger.
Arthur Frederick Phillips.
Frank Stileman.
Archibald Sutter.
Benjamin Frederick Wright.

The following Candidates have been admitted as

Students.

Edward Ernest Cousins.
John Davies.
Alfred Dryland.
Charles Edward Gritton.
William Henry Jordan.
John Brockman Kettle.
Ernest William Moir.
James Musgrave.
James Loftus Owen.
Frank Railton.
Frederick Rawlins.
Leslie Augustus Burton Wade.
Arthur Adlard Welby.

The following Candidates were balloted for and duly elected as

Members.

William Cochrane.
Alfred Christian Downey.
Thorsten Nordenfelt.

Associate Members.

Eduardo Argenti.
William Batchellor.
Edwin Henry George Brewster.
Urban Hanlon Broughton, Stud. Inst. C.E.
James Cleburne.
John Forbes Close, Stud. Inst. C.E.
Alfred James Corry, Stud. Inst. C.E.
Thomas Easton Devonshire, Stud. Inst. C.E.
Robert Ewing.
Frank Graham Fairbank, Stud. Inst. C.E.
Edward Beversham Hanson.
Walter Raleigh Haughton.
Herbert Kyffin Heyland.
Arthur Edward Hight.
George Andrew Hobson.
Arthur Berriman Hoskings.
Percy Edward Keene, Stud. Inst. C.E.
James Braddon McCallum.
John Randall Mann, Stud. Inst. C.E.
Dudley Sinclair Marjoribanks, Stud. Inst. C.E.
Edward Dimmack Marten, M.A.
Richard Pawley, Stud. Inst. C.E.
James Rhind.
Francis Job Short.
John Simmons.
Frederic John Ramsbottom Sutcliffe.
George Gilbert White.

Associate.

John Fletcher Moulton, M.A., F.R.S.

The discussion upon the Paper on "Resistance on Railway Curves as an Element of Danger," by Mr. Mackenzie, occupied the evening.

8 May, 1883.

JAMES BRUNLEES, F.R.S.E., President,
in the Chair.

(*Paper No. 1921.*)

"On the Diamond Fields and Mines of Kimberley, South Africa."

By James Noah Paxman, Assoc. M. Inst. C.E.

Kimberley is situated in Griqualand West, about 700 miles north-east from Table Bay, and is about 450 miles distant inland from Port Elizabeth and Natal on the East Coast.

A railway is open from Table Bay to Beaufort West, which is about half-way to Kimberley, the line being in course of construction for the remaining distance. There is also a railway about 220 miles long from Port Elizabeth to Graaf Reinet. The distance by coach road over open country from Beaufort West to Kimberley is a little over 300 miles, and from Graaf Reinet about 230 miles, the journey from Beaufort West occupying from five to ten days, according to the state of the road, and from Graaf Reinet three to six days.

The principal mines in Griqualand are four in number, viz., Kimberley, De Beer's, Du Toit's Pan, and Bultfontein. Besides these there are a few others, which at present have not been sufficiently tested to hold out a hope of their being rich enough to be profitably worked. The Kimberley and De Beer's mines are about 1 mile apart, on Government property. The other two, Du Toit's Pan and Bultfontein, are about 2½ miles distant from Kimberley in a southerly direction, and contiguous to each other; De Beer's mine is between Du Toit's Pan and Kimberley. There are two other mines in the Orange Free State, namely, Jagersfontein and Koffyfontein. The first of these produces remarkably fine white stones.

The mines are divided into claims, each claim being about 30 feet long by 30 feet wide.

Kimberley Mine contains about . . .		400 claims.
Du Toit's Pan,, ,, ,, ...		1,639 ,,
De Beer's . ,, ,, ,, .	about	600 ,,
Bultfontein ,, ,, ,, ...		1,070 ,,
Jagersfontein ,, ,, ,, ...		1,250 ,,
Koffyfontein ,, ,, ,, ...		1,795 ,,

These mines are all open and are worked from the top; the deepest and most regular is the Kimberley. The next deepest is De Beer's, which is uneven; then follows Du Toit's Pan and Bultfontein. It will be noticed that the largest of the mines in Griqualand is Du Toit's Pan. It is next in importance to Kimberley.

In the earlier workings the claim-holders were very numerous, as no single person could hold more than two claims, many of these claims being divided into holdings of one-half, one-quarter, one-eighth, and, in some instances, one-sixteenth. At first but few whole claims were worked by single holders, especially in the Kimberley mine.

The Author thinks it will not be out of place to describe in what manner diamonds were first discovered.[1] Griqualand West was for many years inhabited by a native tribe called Griquas, first under the chieftainship of Andreas Waterboer, and afterwards of his son Nicholas, who ceded his territory to the British authorities, and it then became a Crown colony. That part of the country now comprising the diamond diggings and mines situated between the Cape Colony and the Free State, or Batlapin territory, is set down in old maps as being inhabited by Hottentots. A portion of Griqua territory was settled upon by colonists under terms made with Waterboer about two years before the discovery of the diamond fields. One of the colonists who had helped to form a settlement was Van Niekirk. Mr. John O'Reilly, a trader and hunter, on his return from further up the interior some time in 1867, called upon Van Niekirk, and remained with him overnight. In the course of the evening O'Reilly's attention was attracted by some bright pebbles found in the Vaal River, with which one of Niekirk's children was playing. He took one of the stones from the floor, examined it, and offered to buy it. Van Niekirk, unaware of its value, refused to sell it, but offered it as a gift. O'Reilly considered it to be a precious stone, and it was ultimately agreed to ascertain its value, and, when sold, to divide

[1] "Diamond Fields of South Africa." By R. W. Murray. Journal of the Society of Arts, vol. xxix., 1881, p. 370.

the proceeds. It was on examination pronounced to be a diamond of 22½ carats, and was next forwarded to the Colonial Secretary to the Government of the Cape of Good Hope. The stone was finally sent to England to Messrs. Hunt and Roskell, who confirmed the opinions previously expressed, and valued it at £500. Mr. O'Reilly then set out to look for more diamonds, and succeeded in finding another stone of 8 carats and one of 8⅞ carats. Many smaller stones were brought in by the natives, and soon a diamond of 83½ carats was discovered. It was christened "the Star of South Africa," and bought by Messrs. Lilieneld Brothers, of Hopetown, for £11,200, and forwarded by them to Messrs. Hunt and Roskell, who sold it to Earl Dudley.

By the end of 1868 many enterprising colonists had pushed their way up the Vaal river, where it was understood diamonds had been found. It was not until some time after that any digging for diamonds took place, as the colonists at first contented themselves with employing natives to search among the top gravel on the river banks. One of a party, however, who had been a gold-digger in California and Australia, suggested sinking a shaft. This turned out a failure, and recourse was had to the plan of cradling, which was carried on successfully upon both banks of the river. The centre of the river diggings on the Transvaal side was Klipdrift; on the opposite side Pniel, the distance between these two centres being about 1,800 yards. The diamonds were found in the gravel which was dug out between boulders, and carried to the waterside and washed.

The "diamantiferous stuff," as it was called, is composed of various earthy matters, with a large admixture of basaltic pebbles, agates, inferior jaspers, crystals, &c., all of which abound along the banks washed by the river, as well as in the river-bed itself. The quantity of soil dug out and washed by a party of ten men was about 6 tons per day. The finds of diamonds were very unequal, sometimes large, sometimes small, frequently nil. Still on the whole the diggers did well, and many large fortunes were made. Shovels, picks, and crowbars were the instruments used for breaking up and collecting the soil. It was conveyed by carts and wheelbarrows, or by buckets and sacks, to the riverside, and there washed in a cradle.

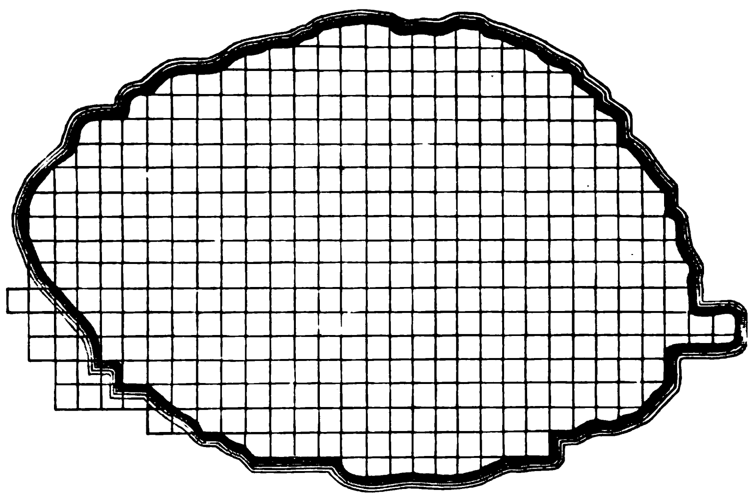
A cradle is a rough box about 2 feet square with rocking feet, and containing two sieves of different meshes; a coarse sieve, which will let pass even the largest diamond likely to be found, while retaining large pieces of stone or pebble, and a fine sieve to get rid of the fine grit and dust. The residue was emptied on a

table and sorted by hand by a scraper of sheet-metal about 6 inches by 4 inches. The sorter would separate as much as he could conveniently overlook from the general heap, spread it out on the table, pick out the diamonds, and scrape the remainder off. Only the surface gravel was worked in these places, which were then abandoned and others tried lower down. There were in all fourteen river diggings.

Before the close of 1870 the camps were swarming with people. Houses and stores were erected of canvas and galvanised iron, and large towns arose on each side of the river.

News arrived that diamonds had been discovered on a farm

FIG. 1.



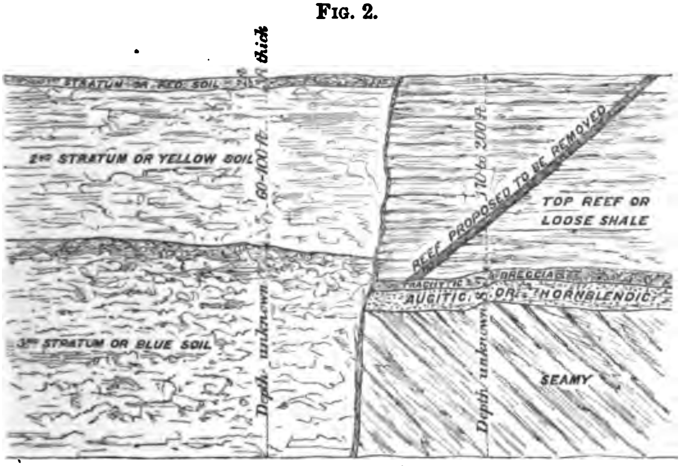
PLAN OF KIMBERLEY MINE.

called Dorsfontein, now named Du Toit's Pan, and on another farm called Bultfontein, about 24 miles distant from the diggings on the Vaal River, and between that and the Modder River. As diamonds were found there in great numbers, the diggers rushed to these places and took possession of them, in spite of all the proprietors could do to prevent them. This kind of proceeding is called "rushing" or "jumping" a mine, and has since occurred in other places. The original owners of Du Toit's Pan and Bultfontein granted licenses at 7*s.* 6*d.* per claim per month, thus giving the first diggers a right to work. Early in 1871 De Beer's mine was discovered, and in July of the same year Kimberley mine. New rushes were made, and many diamonds were found

near the surface. In 1872 Mr. Spalding's great diamond of 282½ carats was found at one of the small river diggings.

As will be seen by the plan of Kimberley, Fig. 1, these mines are of irregular shape, each mine being surrounded by reef. It is only within this reef that diamonds are found. In 1882 the area of the surface of Kimberley mine was 20 acres, 2 rods, 24 poles. Its diameter from east to west was 1,100 feet, and from north to south 1,020 feet. The area of the surface of the claims was 9 ácres, 1 rod, 6 poles, and there were 420 claims of 961 square feet each. A section indicating the formation of the soil of the mine and of the reef is shown in Fig. 2. The top reef is a loose shale varying in depth from 170 to 200 feet; it has given great trouble from the frequent slips which occur in it. Below this lie 3 feet of trachytic breccia,

FIG. 2.



Section of Mine. Outside Mine. Section of Reef.

then 8 feet of compact augitic or hornblendic, and below this it is seamy to an unknown depth, assimilating to basaltic trap, running down almost vertically but slightly inwards. It is believed that the strata underlying the shale are sufficiently strong to withstand the outside pressure; if so, the diamantiferous soil can be extracted without fear of further slips, after the top shale on the edge of the mine has been removed to an angle of 45°. Within the reef, the surface soil, to a depth of 2 or 3 feet at Kimberley and at most other mines, was of a red colour and sandy nature, resembling the well-known Mansfield moulding sand. At Kimberley mine the finds in this were particularly good. The next stratum, varying in depth from 60 to 100 feet, is of the nature of a loose yellow gravelly lime, being in some parts rich

in diamonds. The third is the real diamantiferous stratum, and called from its colour the "Blue." It is of a nature similar to slate, but more easily worked, getting slightly harder as the depth increases. It is less brittle than slate, and more tough and soapy in character. In appearance and substance it resembles dried pipe-clay, though rather darker in colour. Up to the present the thickness of the "Blue" stratum has not been ascertained, although in Kimberley mine it has been worked to a depth of 420 feet, and has been bored into some 200 feet beyond this depth without any signs of reaching the bottom. In the "Yellow" some large stones were found, but generally the working of this bed does not pay, the finds varying in value from 1*s.* 6*d.* to 3*s.* per load of 16 cubic feet. This applies to Du Toit's Pan and Bultfontein mines, and to the soil near the surface, a considerable portion of which does not even yield the above value, and is therefore not put through the wash-mill. The yield increases somewhat with the depth, but on the whole the above sums are not sufficient to cover the entire cost of working. Kimberley mine formed an exception to this rule, the yield in the "Yellow" having been much greater and having paid well for the working nearly all through. The top portion of the "Blue" in some parts of Kimberley mine yielded diamonds to the value of from 15*s.* to 25*s.* per 16 cubic feet of soil extracted; but this yield has since increased, and is at present about £2 5*s.* for the same quantity, and, in some instances, has reached as much as £3 per load.

At Kimberley a method of working in deep ground was first arranged by means of roadways running north and south. These roadways were laid out in such a manner that by taking 7½ feet on alternate sides of the claims, a free space of 15 feet in width was formed, giving one roadway of that width to every two claims. To this roadway the soil was hauled up in buckets by hand by means of a pulley attached to a pole sunk in the ground close to the edge of the claim. Hence it was taken to the owner's sorting tables outside the mine. The roadways decayed soon after being exposed to the atmosphere, and a system of hand-windlasses was adopted. These windlasses were mounted on wooden stages outside and upon the edge of the mine, one above the other, those which worked the farthest claim taking the highest place. Aerial tramwires were used for hauling upon, and the earth was carried in skin buckets supported on a single wire by a travelling wheel. The longest distance pulled by hand-windlasses was 150 yards. The mine soon became wide, deep, and hollow, and in 1873 had been worked in parts to a depth of 100 feet from the surface.

Windlasses gave place to horsewhims, or drums about 10 feet in diameter, which revolved horizontally. These were set in motion by a horse underneath. At first these horsewhims hauled small casks fitted with two wheels suspended upon a single wire; but an improvement was afterwards effected by the introduction of two wires and a tub swinging in a frame supported on four wheels. As the depth increased horsewhims were found inadequate to the task, and steam-engines commenced to take their places in 1876. The first diggers worked, on an average, ten loads a day each party; with the windlasses, fifteen to twenty loads; with horsewhims, sixty to seventy loads, and the first steam-engine erected, which was a 6-HP. vertical, hauled out sixty to one hundred loads. At the present time the least taken out by any engine, when fully at work, is two hundred and fifty loads per day.

The cost of working the first 100 feet in depth by the present appliances averages about 3*s*. 6*d*. per load; the second 100 feet (mostly "Blue"), 5*s*.; the third 100 feet, 8*s*.; and the fourth 100 feet, 11*s*. The increase in the cost of working the two last-mentioned stages is caused chiefly by the slips from the surface, the reef falling into the mines, and having to be removed before the diamantiferous soil can be got at. A tax is levied upon all claims, according to the assessed value, to cover the cost of removing the fall of reef, pumping out water, management, &c.; but the claimholders immediately affected by falling reef always suffer by its interference with their legitimate work, and thus the cost is increased, as stated above. A very large slip occurred in the south-west corner of Kimberley mine in 1880, the clearing away of which has already cost nearly £1,000,000 sterling, and a considerable portion has still to be removed. Another slip, though of less magnitude, took place in the north-east corner in 1882, and it has been decided to clear the whole of the reef away, to an angle of 45° (Fig. 2).

Water has occasionally been very scarce and dear, and has, in times of drought, been paid for at the rate of 10*s*. per barrel of 36 gallons. Water being so difficult to obtain, dry-sorting was in operation during several years. This method consisted in passing the soil through sieves in a rocking cradle, but without washing, spreading the residue on the tables, and sorting it. This system was superseded by the introduction of washing in 1874, and which is now generally employed.

Many and grave mistakes were made at the beginning, which led to waste of labour and capital. Thus the first diggers in the mines, when they had reached the bottom of the red sand, imagined

that no diamonds would be found in the underlying strata, and shifted the refuse soil from one part of their claim to another. When, however, they discovered diamonds in the "Yellow," the whole of the débris of the "Red" in Du Toit's Pan and Bultfontein mines had to be again handled and carried away. Much about the same thing had to be done with a large portion of the "Yellow" soil, when diamonds were found in the "Blue."

When Du Toit's Pan and Bultfontein mines were "rushed" by the diggers, the latter took possession of their claims, 30 feet square, without any regard to regularity or to a general plan, each setting out his ground in the way which seemed most convenient to himself. The consequence was, that with new claims being taken by the side of existing ones, pieces of land were left of irregular shape, and although much was done subsequently, by giving and taking, to rectify this error, the irregularities are noticeable to this day. In the other mines discovered at a later period, advantage was taken of the experience gained, and both Kimberley and De Beer's mines were, from the commencement, properly and regularly laid out and worked.

In one or two instances, in the deep workings at Kimberley, shafts have been sunk and connected with the mine by underground galleries. The earth is conveyed through the galleries to the bottom of the shaft, and then hauled to the surface. These galleries are especially convenient in the case of falls of reef, which carry away or dislodge the wire-ropeways, as work can still be carried on by their means. But shaft-sinking is very costly, and, in one instance which came under the Author's personal notice, a sum of £30,000 was expended in sinking one shaft, and it was computed that the whole of the ground owned by that company could have been cleared out to the bottom of the shaft for a less sum. This is mentioned to show how some of the companies have been brought into difficulties by the incompetency of their advisers.

Native Kafir labour was very cheap at first. The services of a man could be had for his food and 20*s.* per month. In 1880 the cost of labour had risen to 22*s.* per week in money; in 1881 to as much as 30*s.* per week, and food had to be paid for. The food, however, is not of an expensive nature, the natives mostly living on mealies and a little meat.

In the erection of wooden stages for the attachment of aerial wires, hand-windlasses, and horsewhims, it is computed that a sum of nearly £750,000 sterling has been spent in the different mines. Thousands of wires were attached, giving the mines the appearance of gigantic cobwebs. All these appliances have now become

obsolete, and have given place to the modern and improved methods which will be described.

The working of the "Yellow" soil offers no difficulties, as it is of a loose and broken character, and can therefore be directly treated in the wash mill, which, in this case, is generally erected close to the mine. The "Blue" soil is of a different nature, and mostly requires to be blasted, the drilling for which is done by Kafirs, by hand, in the usual manner. The earth is then picked, and shovelled into trucks. These trucks run upon a line of 18 inches gauge, formed of steel rails of small section, principally 12 lbs. and 14 lbs. to the yard, to the place where the earth is tipped into the tubs, which are hauled up on the wire-ropeways. The tubs discharge their contents either into the trucks direct which run to the depositing ground, or into a depositing box, which serves as a reservoir, and from which the trucks are filled. Above the depositing box is placed a fine screen, fixed at an angle of 45°, over which the earth is shot. The coarse particles fall into the depositing box; the finer, which pass through the screen, are conveyed direct into the wash-mill. The trucks filled from the depositing box are run to the depositing ground, some distance away outside the mine. To each claim an acre of ground is allowed for this purpose, Kimberley and De Beer's excepted.

The "Blue" earth is spread out to a thickness of 4 to 6 inches, and exposed to the atmosphere during several weeks. When dry it is well watered, and it slacks into dust similar to lime. It is then gathered up again by hand-labour and put into trucks, which take it to the washing-machine near at hand.

Another method is also employed for carrying the earth from the mine. Instead of transhipping it from truck to tub, and back again from tub to truck, it is run, in the first instance, in the trucks to a lift placed conveniently in the mine; the truck is then raised to the top level, and run to the depositing site. But, owing to the disadvantage of not being able to separate the small stuff, which can be treated in the wash-mill without being first slacked, this arrangement is not generally approved.

It has been mentioned previously that 7*s.* 6*d.* per month per claim was paid, for a license to work, to the owners of Du Toit's Pan and Bultfontein mines. Some years afterwards considerable litigation took place between the diggers and owners on that point, and it was ultimately agreed, with the sanction of the Government, that 30*s.* per month per claim was to be paid, which included 1 acre per claim for depositing. This arrangement also

gave the diggers fixity of tenure, which they had not enjoyed previously, and whereby they were enabled to dispose of their interest in the claims when they desired to do so.

Du Toit's Pan and Bultfontein mines were bought by the founders of the South African Exploration Company for a little under £5,000. Their income from royalties on claims, depositing sites, and other grounds and rents in the two townships, &c., amounted, in 1881, to £108,000. In Kimberley and De Beer's mines the claim-holders pay only 10*s.* per claim per month, but they have to provide their own depositing grounds. The two mines are on one farm, which was, in the first instance, sold for £6,000, and purchased by the Government for £100,000. They are now, for taxing purposes, assessed at £1,500,000 sterling.

As regards the individual claim-holder, he is dependent very much on fortune, for the claims, although they all pay the same royalty, are unequal in value. In some claims large yields have been obtained near the surface, while the lower strata have not been nearly so rich as was expected. In others, the case was reversed; and again, in other claims was found what is called floating reef, which is devoid of diamonds.

In 1876 the steam-engine was first introduced at the mines. It was of a vertical type, and was the forerunner of many others of the portable and semi-portable kinds. Among others the Author also supplied machinery; but, beyond the fact of knowing that fuel and water were both scarce and dear, he was during several years unaware of the real requirements of the case. In 1878 the cost of wood, the only fuel used at that time, had within a short period risen from £7 per load of 5,000 lbs. to £14. This quantity is, for heating purposes, about equal to 1 ton of good coal. Since that time the gradual clearing of the forests in the vicinity, and the consequent necessity of a longer transport, has brought the cost up to £21 per load.

Another serious item of cost is the transport of machinery over a long distance in open country, with natural roads only, usually performed by oxen, nine pair to a wagon, carrying a load not exceeding 10,000 lbs. The cost of such transport amounts to from £15 to £30 per ton.

In 1881 there were actually at work at the four Kimberley mines two hundred and three steam-engines; while twenty-nine more were being fixed or were unemployed, making two hundred and thirty-two. It was computed that there were also seventy-five steam-engines at the other mines, raising the total to three hundred and seven.

The cost of wood consumed, for the two months of January and February, was £24,650. At the same ratio, a twelvemonth's consumption would amount to £24,650 × 6 = £147,900, and with the considerable increase taking place, might be computed to be not far from £200,000. But, even when taken at the minimum sum of £147,900, the consumption per engine of fuel at the Kimberley mines would amount to $\frac{147,900}{203}$ = £728 11*s.* per annum.

The total nominal HP. amounted to 1,844, giving an average of $\frac{1,844}{203} = 9 \cdot 08$ HP. per engine.

It may be safely assumed that one-half of these engines were only partially employed, so that the fuel charge per fully-worked engine would probably amount to about £97 per HP. per annum; or, taking the year at three hundred working days, and ten hours per day $= 0 \cdot 64$*s.*, or 7½*d.* per nominal HP. per hour.[1] It became evident under these circumstances that machinery of a superior character was required, and this led to the introduction of that about to be described.

Description of Machinery.

In designing the special machinery, of which various diagrams are shown, particular attention was paid to the following points:—

1. Simplicity, to facilitate the execution of repairs in places where skilled labour is scarce and dear.

2. Effective strength of parts, combined with a minimum of weight, to save expense of transport, which forms so large a portion of the cost at the fields.

3. Construction of engine-frames in such a manner that they might be put down readily without foundations, which are very expensive, owing to the scarcity of building materials and the high cost of labour.

4. Fuel being very dear, the engines had to be designed to give the greatest amount of duty for the fuel consumed. Wood being the fuel principally used, the fireboxes had to be of suitable dimensions.

5. In regard to water, which at times is scarce and expensive, the same attention had to be bestowed upon its economy as upon that of fuel.

Two types of hauling-engines are shown in Plate 1, Figs. 1 to 4,

[1] Twice the nominal is about the effective HP.

the direct-acting engine and the geared engine; also a semi-portable engine for driving the wash-mill and apparatus connected therewith (Plate 1, Figs. 5 and 6).

The direct-acting engine (Plate 1, Figs. 1 and 2) is complete upon its frame, which is of wrought iron or steel, and attached to timbers ready for being set in position. The winding-drums are mainly of wrought iron. This engine works with 80 lbs. steam-pressure per square inch, and a piston speed of 300 feet per minute. It will haul eight hundred and fifty loads of 16 cubic feet each per day of nine hours a maximum distance of 200 yards. It is of 16 nominal HP. It is by many preferred to a geared engine to save weight, and to haul the same load at an increased velocity. When desired, the wrought-iron frame is increased in depth sufficiently to dispense with the timber framing, and is so made that it requires no further foundation, but can be put down and the engine set to work in the loose soil.

The geared engine (Plate 1, Figs. 3 and 4) is complete upon its frame and is attached to timbers. It has steel gearing in the proportion of 1 to 3 attached direct to the wrought-iron winding-drum, a brake-strap in some instances acting on the fly-wheel, as well as upon the rim of the drum. It works with 80 lbs. per square inch of steam-pressure, and can haul at the rate of 600 or 700 feet per minute. It will drag six hundred loads of 30 cubic feet each per day a maximum distance of 200 yards. The engine here shown is of 25 HP.

As the loads vary from 16 to 30 cubic feet in capacity, it is evident that the power provided must be sufficient to haul the load decided upon at the rate which may be desired. In both types of engines the crankshafts, the crosshead, crank, and link pins, and the keys and bolts of the connecting rods, are of steel. With skilful stoking and careful attendance these engines do not consume more than 4 lbs. of coal per HP. per hour, or 8½ lbs. of wood, and this for actual weight hauled out of the mine.

The engines above described are provided with a water-heater of light and strong construction, the barrel being of wrought iron. Inside the barrel, which is 6 feet long, a number of 1-inch tubes extend the entire length. The steam passes through the tubes, and the feed-water circulates outside. It will be readily understood that much of the steam becomes condensed; a water-catcher is therefore attached to the heater for collecting it. By this means, with a regular feed-supply to the boiler, 33 per cent. of the water is returned. This heater is constructed on the Biddle and Balks boiler principle, so that by breaking the joint at each

end, the whole of the tubes and the tube-plates may be easily withdrawn for cleaning.

The boilers are of the semi-portable or locomotive type, and are now made almost entirely of steel, to save weight.[1] When wood is burned the fireboxes are constructed of extra length, to save the labour of cutting up the wood into short pieces. The fireboxes are now made of a mild and very ductile steel, which can be welded. Great care is bestowed in working and annealing it.

In the semi-portable engine (Plate 1, Figs. 5 and 6) which drives the wash-mill, the boiler and engine-frame are made of steel. The engine-frame is bolted to the boiler by four angle-irons, which arrangement allows the whole engine to be taken off the boiler for convenience in transit, and it can be fixed separately if so desired. The engine may be worked with a steam-pressure up to 140 lbs. per square inch, running at the rate of a hundred and forty revolutions per minute. The cylinder is $8\frac{1}{4}$ inches in diameter, with a length of stroke of 12 inches, and this engine can be worked with great economy up to 22 HP. The boilers of this type of engine are made of mild steel, as are also the fireboxes. The engine is provided with Paxman's automatic cut-off controlled by the governor. The cut-off valve is three-ported, and placed within a separate or outer jacket behind the main valve. The cut-off gear consists of a short link, acted upon by two small eccentrics, of which the one that opens the port may be called the positive, while the other, set at a different angle, and which cuts off, may be called the negative. The travel of the positive eccentric is $1\frac{1}{4}$ inch, and of the negative $\frac{9}{16}$ inch. As the link is lifted this travel is gradually reduced, and by this arrangement any degree of admission of steam from nil to $\frac{3}{4}$ of the stroke may be obtained with a sharp cut off, while the lead is constant. It has been found by practical experience that a cut-off at 21 per cent. of the stroke is the most economical when working with 140 lbs. of steam-pressure per square inch, and while running at the rate of about 280 feet of piston speed per minute. The three sets of diagrams (Figs. 3) are accurate representations of diagrams taken while the engine was running at full speed.

The winding-engines are now made of compound type with the automatic cut-off similar to that just described. A condenser is also recommended, as the water can be stored in a tank and used for washing. When working with 80 lbs. steam-pressure, it is

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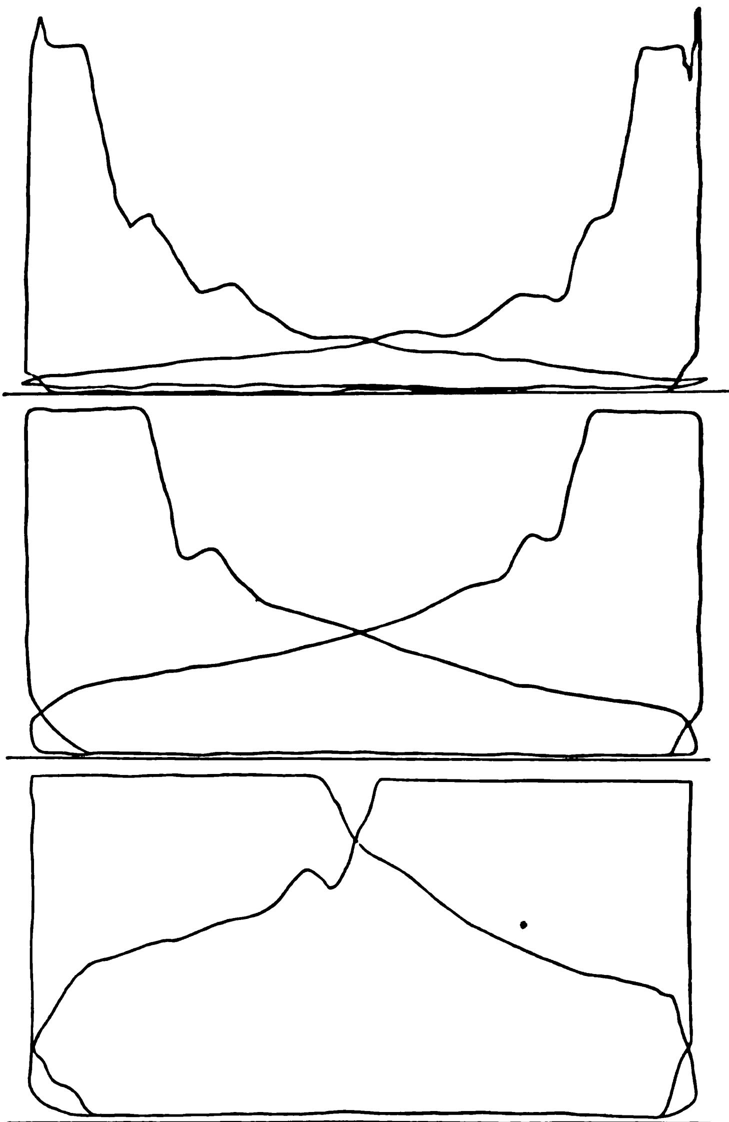
[1] A comparison of the weights of engines with steel and into iron gear is given in the Appendix.

Figs. 3.



Scale ½.

Indicator Diagrams, with Automatic Cut-off Gear.

Steam-pressure, 120 lbs. per square inch. Piston-speed, 280 feet per minute.

advisable to make the area of the cylinder sufficiently large, and the machinery strong enough, to do the duty required when cutting off at 25 per cent. of the stroke. The saving both in fuel and water by this arrangement well repays the extra cost.

When wood gradually rose in price, coal was sought after and found on the borders of the Rhenoster river, in the Cronstadt district, Orange Free State, about 150 miles N.E. of Kimberley. It emits a good deal of smoke, but burns freely without forming clinker, leaving a small amount of clean ashes. The cost of transport by ox-wagons is £10 per ton. The coal is now sold at £13 per ton. The wood is of high specific gravity, some of it being almost like ebony or lignum vitæ, which makes it very suitable for the bearings of tubs, wagons, trucks, &c. It is found in practice to wear better than the hardest gun-metal. When used as fuel it burns freely; its heating power, compared to coal, being 2¼ lbs. of wood equal 1 lb. of good coal.

The wash-mill, the screen or cylinder, and the elevator, in combination with the rest of the plant, are shown in Plate 1, Figs. 7, 8, 9, 10 and 11. Till recently most of the standard frames were constructed of wood; now they are made of wrought iron. The cylinder A is 3 feet 6 inches in diameter by 10 feet in length. It is inclined, receiving at its upper end, A 1, the diamantiferous soil, and discharging at its lower end, A 2, such pieces as have not passed through the meshes of the screen. The central part of the screen proper is formed of flat steel bars, placed radially on the periphery, leaving thus long slots 1⅛ inch wide, which are again subdivided by steel rods ⅜ inch in diameter, set at 1½ inch pitch, each rod forming a ring which passes through holes drilled in the flat bars. The screen has thus spaces 1⅛ inch square, through which the sludge falls upon a shoot which conveys it to the wash-mill. The screen is rotated by two pairs of bevel wheels and an intermediate shaft from the horizontal shaft placed over the wash-mill, and makes forty revolutions per minute.

Washing-machines, principally of the rotative kind, of from 6 to 15 feet in diameter, were introduced soon after the washing process was resorted to. Sometimes they were made with step bottoms. At others with divisional plates and steps, forming, as it were, a double mill. In these the material is fed in at some part of the periphery; but this mode of arranging the pan has been found by experiment not to be safe, many diamonds being passed out. The cylinders or screens were made with wrought-iron bars, placed longitudinally to support No. 10 B.W.G. steel-

wove wire of 1 inch mesh, but they were soon worn out, and had to be frequently renewed.

Other systems of washing have been tried, such as passing the sludge in a very diluted state down channels and over numerous ledges and traps; but they were not found suitable, partly because they were liable to allow small stones to pass away, and also because a much larger quantity of water was required for washing.

The washing-machine now considered the best was in part designed by the late Mr. Stonestreet at Kimberley in 1879, and was called the umbrella washing-machine, from the fact of the feed taking place from a central hopper into a series of radiating channels placed upon a revolving cone, the flow thus passing from the centre towards the periphery. As modified by the Author and Mr. Thaine Allen, the wash-mill pan B, of circular form, is made of steel $\frac{1}{4}$ inch thick, and is about $13\frac{1}{2}$ feet in diameter by 2 feet in depth. It is in the form of an inverted cone with conical bottom rising towards the centre C, where a narrow upright ledge and a central aperture allow the lighter sludge to pass away. The pan itself is a fixture. Within it turns an agitator D which keeps the whole mass in motion. The agitator D consists of a number of arms, of channel section $\sqcup$, bolted to a central boss, and extending radially nearly to the periphery of the pan. Upon these arms are mounted a number of vertical steel stirrers E E E, set at different distances from the common centre in such manner that, at each rotation of the agitator, every part of the bottom of the pan is passed over, and the earth or sludge disturbed and displaced. The agitator is attached to a vertical shaft F, which turns at the rate of fifteen revolutions per minute, and is driven by a pair of bevel wheels from the horizontal shaft G, which receives its motion by pulleys and strap from the semi-portable engine. Above the agitator is placed the central hopper H, into which passes the sludge from the screen. This hopper is attached to the vertical shaft F, and turns with it, and from it issue a number of channels J J J, extending radially nearly to the periphery of the pan. The ends of these channels rest on, or are attached to, the circular frame of the agitator, and they thus deliver the sludge to near the periphery of the pan. At the end of the day's work a sliding-door K, extending nearly across the bottom of the pan on one side from the periphery and central aperture, is opened, and two broad scrapers, L L, which are attached to two of the agitator arms, but which are not set radially, but at an angle to the centre, are let down to nearly the bottom of the pan, while the mill is in motion, sweeping the whole contents of the pan into a truck, M, on wheels,

placed under the opening made in the bottom. The elevator, some 20 to 30 feet in height, is fitted with steel buckets, and driven by an endless chain from the same shaft as the screen. The jumper preferred consists mainly of a double standard frame, which carries adjustable pieces, of segment shape, one for each wire rope, and also a central roller or pulley to guide the hauling-rope. These jumpers are placed at any points where, from the nature of the ground, a change in the angle of the standing wire-ropes becomes necessary.

The tubs (Plate 1, Figs. 12, 13, 14) are of steel, and are hung on trunnions, supported upon a frame resting, by two grooved wheels upon each side, upon the wire ropes, the tub thus preserving its vertical position, no matter at what angle the wire ropes are placed. The tubs can be emptied in an automatic manner by means of a hook attached to the front, which catches in a cross-bar placed at the point where the discharge is to take place. In practice, however, it is considered safer to have an attendant to perform the operation of placing the hook. Steel wheels were at one time tried with the tubs for running on the wire-ropes; but they were found to seriously injure the wire strands, and wheels of soft cast iron are now preferred.

The four wire ropes, called standing-wires, are fixed at some point at the back of the machinery, and are led over a frame, fixed at the top of the mine, to a convenient spot in the mine, where the tubs are loaded. At the upper end, near the machinery, the standing-wires, of which the extremities are attached to straining screws (Plate 1, Fig. 15), are passed round pulleys. These screws penetrate wooden beams attached to posts firmly fixed in the ground. The ends of the wire-ropes are passed round the pulleys and fastened by a strong wrought-iron clip. A similar clip is used for holding the ends at the extremities of the standing wires in the mine. The ends are fastened to wooden posts, placed about 24 feet beyond the spot where the tubs are charged. The posts are fixed at the bottom of pits, sunk to a depth of 15 feet below the surface, thus enabling the ground to be excavated to a depth of 25 feet without shifting the posts. It is necessary for the wires to have sufficient inclination to cause the empty tubs to run down by themselves, so soon as the strain upon the hauling-rope which brought it up has been taken off by the reversal of the winding-engine. The standing-wires are from $1\frac{1}{4}$ inch to $1\frac{5}{8}$ inch in diameter, and are made of the best crucible-steel wire. The life of standing wires is from five to seven years.

The hauling-ropes are from $\frac{7}{16}$-inch to $\frac{3}{4}$-inch in diameter, and

vary in size according to the load. These, also, are made of the best crucible-steel wire. Good ropes will haul about seventy thousand loads before wearing out. The hauling-ropes run in the central grooved friction-wheels of the main standard and of the jumpers, and V-shaped pieces of bar iron of half-round section are provided, which guide the rope back into the grooved wheels, whenever it has been lifted out by the passage of a tub over a jumper.

When a tub ascending from the mine approaches a jumper, the flanges of the wheels upon which it rolls mount the segment-shaped pieces in such manner that the whole weight of the tub is taken off the ropes and temporarily supported by the segments. This is to prevent the injury of the ropes by jamming between the wheels and their supports. After the passage of the front pair of wheels beyond the angle in the ropes, they gradually settle down again upon the standing-wires. In descending, the empty tubs act in the same manner, and the hauling-rope, guided by the V-shaped pieces, gradually falls into the central roller.

The method of treating the diamantiferous earth is as follows:—After the "Blue" soil has been blasted and collected into trucks, it is emptied into tubs, which latter ascend on the standing wires, traverse one or more jumpers, and are emptied into the depositing box. The remainder of the "Blue" is then exposed on the depositing ground and slacked, and is delivered into the upper part of the screen or cylinder at A, into which also is discharged the return-water from the elevator with a portion of fresh water. The admixture of water at this point considerably facilitates operations by thoroughly saturating the soil, and assisting it to pass down the shoots. The pieces which are too large to pass through the meshes of the screen, are discharged at the lower end into trucks and carried away. A man is generally stationed at that point, however, to watch for large diamonds. The smaller pieces and the water pass through the screen in the form of sludge, and fall into the shoot N, and thence into the central revolving hopper H. The sludge flows down the channels, and is discharged at the periphery of the wash-mill pan into the mass, which, by the rotation of the agitator, is kept in constant motion. Two forces now come into play; gravity and centrifugal force. The diamonds, and other pieces of high specific gravity, sink, and are urged towards the periphery of the pan, where they settle in the deepest part, while the remainder of the sludge is gradually forced over the inner ledge, and runs down the channel to the elevator. Here the sludge is lifted and thrown upon an

inclined screen O. This allows the water to fall through into the return-shoot P, which conveys it back to the upper part of the cylinder. The water is thus used over and over again, not only on account of its comparative scarcity, but also because thick, dirty water, being of greater specific gravity than clean water, has been found more suitable for the washing process.

The more solid portion of the sludge flows over the screen O, and down the shoot, and is discharged over the side of the bank. It frequently becomes necessary to raise an artificial bank to prevent the sludge running back to the machinery, and, in the absence of cheaper building material, it is formed of bags filled with earth. The quantity of soil treated by the wash-mill of the size shown in Plate 1, Fig. 7, in a day of nine hours, is about eight hundred and fifty loads of 16 cubic feet each, or 13,600 cubic feet.

The residue left in the pan amounts to about 30 cubic feet, and this quantity is then passed through an apparatus called a "pulsator," in which there are a series of sieves of different meshes. Water is pumped in at the bottom, flowing upwards through the sieves at a suitable velocity to carry off the mud and lighter particles, and leaving diamonds, garnets, agates, and other heavy stones. The specific gravity of the diamond largely exceeds that of any other stone found with it. The residue from the washmill is thus reduced to about half its bulk, from 45 to 60 per cent. being removed, leaving only 40 to 55 per cent. to be taken to the sorting tables. To test the efficiency of the machinery, it is the practice to put a few inferior diamonds, small, and of peculiar shape, easily recognised by the watchers, promiscuously with the diamantiferous earth. Such diamonds are called test-stones, and are invariably found again among the residue of the wash-mill pan. They vary in size from 1 carat to 10 carats, and are occasionally even larger.

In conclusion the Author may state that in 1881 he paid a visit to Kimberley, and, on his arrival, found that this industry far exceeded his expectations. Two hundred and three steam-engines were at work in the Kimberley mines, varying from 4 up to 30 nominal HP. Several thousands of trucks were in use, and many miles of rails had been laid from the mine to the numerous depositing sites.

The inhabitants of Kimberley and Du Toit's Pan numbered thirty thousand, about twenty thousand of whom are coloured, and it was one of the busiest places to be found. According to the Post Office returns in 1880, not less than £3,685,000 worth of diamonds are sent through the office in one year. Add to this

those brought home by merchants and travellers returning from the fields, and the total will not be short of £4,500,000, a return which is probably not equalled by any other spot of the same size on the face of the globe.

That there are drawbacks to this great industry will be readily understood, and in the Author's opinion, the principal one has been the illicit traffic in diamonds, carried on by a set of persons known as the I.D.B.'s (illicit diamond buyers). The laws relating to these have been, until lately, rather lax, but a Bill passed by the Cape Government last year, introduced much more stringent measures, and, combined with a system of search, lately proposed, will, it is hoped, effectually check this nefarious traffic. So great had been the losses from robbery, that a committee of inquiry, comprising the best authorities in Kimberley, was formed to investigate this matter. They found that the total sum received by the rightful owners was slightly under £2,000,000, whereas it is proved, since the introduction by the Government of the more stringent rules, which now impose a duty of ½ per cent. upon all diamonds leaving the country, that nearly £5,000,000 worth of diamonds are exported in a year; which shows that the difference of £3,000,000 worth of diamonds had been illicitly bought by the I.D.B.'s.

In the opinion of the Author this industry is likely to last for at least a century, and if it will ever cease at all is a moot question. Some geologists hold that the copjes or mines have been forced up by volcanic action from a large underlying bed far down, and that as the present mines are being worked out, they become, as it were, shafts by and through which the lower, and probably the richer, strata can be reached. At all events Kimberley mine may be said to be little more than begun, and in the other mines only the surface has been worked off as yet.

South Africa is, at the present moment, the only part of the globe in which many diamonds are found, and the value of the yield in the course of a year seems but an insignificant sum when compared with the income of the world and its ever-increasing population and accumulating wealth. There appears to be but slight probability of diamonds becoming permanently cheaper. The railways in course of construction, which will ultimately bring the diamond fields into direct communication with Cape Colony and with the ports on the east coast, are expected to be completed within about two years.

Waterworks have recently been constructed which have proved successful, and which will enable water to be sold in Kimberley

at 1*s.* per 100 gallons. The opening of the railway will be followed by a fall in the cost of the necessaries of life, and of raw materials, which are now very dear. Deals, 9 inches by 3 inches, are sold at 2*s.* 10*d.* per lineal foot; iron bars and plates at 6*d.* per lb.; and rails, trucks, &c., in like proportion. All these anticipated advantages, together with amalgamation, cheaper labour, and materials, improved appliances, efficient machinery, careful management, and better supervision, cannot fail to exercise a most beneficial influence upon this industry.

There is much room for the judicious employment of engineering talent, as well as for the permanent investment of large capital, both of which will doubtlessly be attracted so soon as the fields can be more easily reached than heretofore.

A scheme of amalgamation is being promoted by which all the interests in each mine are to be consolidated. Eventually, it is believed all the mines will be amalgamated, and by this means the working will be more effectually regulated. Thus it is anticipated that a great and prosperous future lies before this enterprising community of diamond diggers in the Cape Colony.

The Paper is illustrated by several diagrams from which Plate 1, and the woodcuts in the text, have been prepared.

[APPENDIX.

APPENDIX.

Weights of Steam-Engines with Wrought-iron Frames and Bed-plates and Steel Boilers unpacked.

	Tons.	cwt.	qrs.	lbs.
8 HP. High pressure semi-portable, with large firebox	2	16	0	14
8 HP. High pressure portable wrought wheels and carriage, and large firebox	3	8	2	21
10 HP. Horizontal geared engine and boiler, with steel and wrought-iron winding drums and gear .	6	7	1	0
16 HP. Horizontal geared engine and boiler, with steel and wrought-iron winding drums and gear .	7	10	2	7
Double steel and wrought winding drum, with steel shaft and gear, each drum 5 feet in diameter by 16 inches wide	1	2	0	0
Double steel and wrought winding drum, with steel shaft and gear, each drum 6 feet in diameter by 18 inches wide	1	10	0	14
	22	14	3	0

Weights of Steam-Engines with Cast-iron Bed-plates or Frames and Wrought-iron Boiler unpacked.

	Tons.	cwt.	qrs.	lbs.
8 HP. Ordinary semi-portable, with large firebox . .	3	11	3	0
8 HP. Ordinary portable, with wrought wheels and carriage and large firebox	4	8	0	21
10 HP. Horizontal with cast-iron bed and cast iron drums and gear	8	13	3	7
16 HP. Horizontal with cast-iron bed and cast-iron drums and gear	10	17	2	0
Double cast-iron winding drum, cast gear and wrought shaft, each drum 5 feet in diameter by 16 inches wide	2	1	0	14
Double cast-iron winding drum, cast gear and wrought shaft, each drum 6 feet in diameter by 18 inches wide	2	18	1	0
Tons—	32	10	2	14
Deduct Tons—	22	14	3	0
Thus making a saving in weight of or 30·105 per cent.	9	15	3	14

[Discussion.

Discussion.

Mr. W. H. HUDLESTON said he had never been in South Africa, and could only speak of the geology of the subject from having studied the papers read before the Geological and other Societies, from which he gathered that the mines referred to in the Paper were the only ones in South Africa worthy the appellation of mines. A distinction ought always to be made between true mines or dry diggings and the old river diggings. The peculiarity of the South African diamond mines was, that they were really mines, and not diggings in diluvial soil like those in many other parts of the world. They could be followed to a considerable depth below the surface, and that constituted their great value and importance. The Author had stated nothing about the nature of the shales or reef in which the diamond-bearing rock was situated. The great mass of the surface rocks consisted of what were called the Karroo Beds, which, in many places, were carbonaceous, containing a considerable quantity of coaly matter, a constitution of great importance in considering the possible origin of the diamonds in the rock. On the north side of Kimberley mine he believed the Karroo shales extended to a depth of 285 feet, or 100 feet lower than the Author showed it in his section. The Author had said nothing about the carbonaceous character of the shales, but in describing the lower rock, 280 feet from the surface, outside the mine, he called it "seamy," the meaning of which he would, perhaps, explain in his reply, as also the meaning he attached to the terms "augitic" and "hornblendic," which Mr. Hudleston did not understand. The composition of the rock below the shales was of great importance for the future of the diamond mines of Kimberley and elsewhere. There was no decided account of its composition, but, so far as he could make out, it appeared to be a basalt. It would be a great advantage to have a better description of it, to know whether it had ever been pierced through, and whether the shales had been found below it. It was not impossible that the carbonaceous shales, so abundant, and so characteristic of the reef above the "seamy" or hard rock, would also be found below it. With regard to the section of the mine itself, the yellow rock or soil was nothing but the blue soil which had been altered by surface action; the upper portion of it had had a certain quantity of its lime extracted by a capillary action common in hot countries where sudden rains fell. The stratum of blue soil was, of course, the true diamond rock, as to the composition of which the Author had Mr. Hudleston.

Mr Hudleston. given no account. He believed it was a rock without any parallel in the world. It might be described as a breccia containing an immense quantity of broken pieces of shale, boulders, and different kinds of basalt. He took it for granted that the diamond rock was an eruptive rock. The matrix containing all the stuff he had mentioned, including the diamonds, was a hydrous magnesian silicate, which was in composition between talc and serpentine. If the absolute nature of the rock were understood, a better idea of the possibilities of the occurrence of diamonds at very considerable depths would be obtained. At a depth of 420 feet the blue rock remained the same; but at 500 feet the character of the rock, and the quantity of water it held were very different. The diamonds were much whiter; and the rock was much more crystallised. With reference to the origin of the rock, and the possibility of its continuing to a considerable distance, it had been held by some authorities in the Colony, including Mr. Dunn, that the volcanic rock had passed through the carbonaceous shales, and that the carbonaceous shales had yielded, by a process of chemical action, the diamonds to the steam generated in the igneous rock. If that were the case, diamonds could not be expected below the point where the shales existed, and the question was, therefore, a very important one to consider. Another theory was, that the eruptive rock had brought up diamonds from some gneissic rock at a considerable depth below. That, however, was a pure hypothesis. If it were true, the owners of the mines had an Eldorado indeed; they had nothing to do but to bore through the igneous rock until they arrived at the great gneissic mass, full of diamonds, like the valley in the tale of "Sindbad the Sailor." Mr. Dunn's theory, however, was quite as likely to be true as the other. Whichever theory was the correct one, Mr. Hudleston cordially agreed with the Author in considering the prospects of diamond mining in South Africa, from a geological point of view, as eminently satisfactory.

Mr. Willcocks. Mr. George Waller Willcocks placed on the table some photographs and geological specimens from Kimberley, which he had obtained while he was connected with the waterworks there. It was remarkable that the Kimberley mine on the south side was often in a state of smoulder, and looked like a heap of burning ballast. That, he believed, came from the pyrites existing in the shale. In the French shaft, sunk in the reef of the mine, fire-damp was found, and the ordinary safety-lamp had to be used as in coal mines. With reference to the Karroo series, in excavating for the rising main, which ran nearly north

from Kimberley to the river Vaal, the trench skimmed through the whole of the surface ground, and afforded a good idea of the differences that occurred in the district. Nearer Kimberley the trench cut through the shale and rotten limestone, evidently coming from the decomposition of the trap-rock, which contained a good deal of lime. Further on came the black shale and a great amount of sand. There had been found in a "pan" a stratified sandstone, which evidently belonged to the Karroo measures, with the shales lying alongside. Those beds, he believed, were the coal-bearing rocks of South Africa, the same kind of rocks that were found in the Stormberg, where the trap burst through the coal measures and overflowed, giving rise to the well-known Table Mountains of South Africa. There was no doubt that the overflowing of the trap which had occurred in South Africa had in many cases preserved the coal from denudation. He should not be at all surprised if in a few years coal were found comparatively near Kimberley. There was at present much talk of the amalgamation of the Kimberley mine; but the main thing to be done was to put the mine ship-shape. It was now in what an engineer would call a rather "dirty" condition, and it was continually slipping. When he was there in September a slip had occurred one night, and there was a fissure in the street 30 feet deep. Considering that the entire depth was 400 feet, the amount of slip which would occur might be imagined. He had just learned that another slip had occurred which would take nine months to remove, at a cost of £200,000. The great mistake had been that the Companies had been working below for the diamonds, neglecting the part above, and that had led to the financial difficulty in which they were placed. He differed from the Author as to the wire-ropeway being better than the shaft. It was stated in the Paper that a shaft had cost £30,000 to sink, and that the amount of stuff was not worth that sum. Nothing, however, was said as to the size of the shaft, the rock formation, or whether it contained water. At Kamfer's Dam, a new mine had been started about 3 miles north of Kimberley, where a shaft had been sunk in the reef away from all slips, and a tunnel driven out into the diamantiferous ground, and worked in the same way as some of the chalk pits were worked in Kent. There were trap-doors in the roof of the tunnel, and the stuff was shot through them into the trams below, which were pushed back to the shaft, and hauled to bank. He thought there was more danger in a wire-ropeway than there was in a shaft. There was no fear of the trams leaving the road, but the tubs often jumped and produced fatal results. He thought Mr. Willcocks.

Mr. Willcocks. that the system of "shaft and tunnel" would be cheaper than wire-ropeways, and it was certainly far more convenient. Of course, it was not necessary to sink 400 feet at once; the companies could sink 60 feet at a time, working out each gallery while proceeding. There were three shafts in the Kimberley mine. One was the French Company's shaft, which had been well spoken of. The Central Company had also a shaft that had succeeded; and there was another sunk in De Beer's mine, which was still working. He thought the days of wire-ropeways were at an end, and that in future diamond mines would be operated by companies who, having capital, could afford to sink shafts and so bring stuff to the bank more cheaply than at present. The Author had not over-estimated the cost of materials in Kimberley. The prices were startling to an English engineer. He had known the price of masonry to be as high as £8 per cubic yard in ordinary common lime, and £13 in cement, and the work could not be done more cheaply. The cost of carrying water to the place to mix with the lime amounted to many shillings per cubic yard. He considered that Kimberley, with its diamonds and engineering works, was a most interesting place to engineers.

Mr. Carter. Mr. W. H. Carter could confirm the statement of Mr. Willcocks that the shale was carbonaceous to a very high extent. On the south side, the shale round the mine, when exposed, was quite black. For a long time it had been burnt to a rusty colour. He could also confirm the statement as to the fire-damp. He was aware that thin seams of coal had been found, but though he did not know exactly where, he believed it was in the shale. The blue rock had been much altered by the action of water, but for which it resembled very much a volcanic rock at Arthur's Seat, near Edinburgh. The minerals, occurring in the fissures and occasional cavities pointed to the conclusion he had mentioned. It was further confirmed by the frequent occurrence of garnets, which almost always appeared along with the diamond at the end of the washing process. Generally the blue stuff brought up was thrown into a box, without the intervention of a screw, to which trucks and carts could be pushed, and the material was drawn from the box into them, as it is not commonly considered expedient to wash even the fine blue without previous weathering. One reason for using muddy water in the machine was, not so much its greater specific gravity, as the fact that the alkali derived from the highly altered rock made the water extremely soapy, so that it formed a lubricator for the stones in the machine. If the lubricator was not present, and fresh clean water was turned

on, this often caused the machine to stop, straining the machinery severely, and sometimes breaking it.

Mr. R. W. MURRAY said he had had the opportunity of watching the progress of the diamond fields from their commencement to the time he left the country, but he was unable to speak either of engineering or of geological subjects. If some of the members of the Institution of Civil Engineers had been there at an earlier period, to teach the people how to set to work, a great deal of money would have been saved. The curse of the country had been the action taken by uneducated non-professional men. Rude machines had been constructed, each destroying what the other had effected. Geologists, too, had made predictions which had been generally falsified. One geologist, who had visited the present diamond fields, declared that there could not be a precious stone in the country; and another said that there could be no gold on the very spot where it was now being worked. The diamond fields had proved beneficial to other districts not belonging to them, which had been able to carry out undertakings that otherwise would never have been attempted. In 1879 the number of native labourers who had been employed was 643,343. These men, who had never before worked for a day's wages, had been earning on an average 22*s.* a week. Many of the natives, on their first arrival, were naked and half-starved, but they lived among the European population, and acquired civilized habits, and they were better than European labourers who had been brought out to do the same work. They built schools and churches, and learnt among other things to speak English. Four distinct towns had been established, one of them administering a municipal revenue of £25,000 a year, raised by a rate levied chiefly upon landed property. When the fields were first established £1 notes in the Orange Free State were fetching from 5*s.* to 7*s.* 6*d.*; the people were only cultivating just enough to live upon, and were extremely poor; and in the Transvaal the inhabitants were in a still worse condition. The two States had obtained a new market in the diamond fields; they increased their cultivation, and were now in a good position. Natal also found a new market for its produce, sugar and copper. There was a vast future for South Africa, and a wide field for engineering work. He hoped that English engineers would turn their attention to that country. He believed that a much larger quantity of diamonds would be obtained than Mr. Dunn had predicted, or than geologists had expected. The value of the annual find had been estimated at £25,000 when only rude machinery was employed, but after the dry diggings were

Mr. Murray.

Mr. Murray. discovered, and better machinery had been brought into play, for the first two or three years the increase was about £500,000 a year until the amount reached about £5,000,000. A great deal of the diamond stealing had been put down, but it had not been entirely suppressed, and he believed that much more than £5,000,000 worth of diamonds was sent home every year. He submitted a model of the Porter Rhodes diamond, which had been estimated as worth £300,000, though no purchaser had at present been found. The diamond resembled a hailstone with fire in the centre. It had been found at a depth of 350 feet. The diamond fields had had much to contend with from the statements of interested parties, and from the ignorance prevailing in England with reference to South Africa. It should be remembered with regard to the £5,000,000 worth of diamonds sent home, nearly half the amount was spent in the manufacturing districts of England, and went back in the shape of corrugated iron, machinery, and manufactured goods of various kinds.

Mr. Beaumont. Mr. W. W. BEAUMONT asked the Author whether the system he had described of dealing with the "Blue" was the one most employed, and whether any attempt had been made to deal with the material as Mr. Crampton had proposed to do with the stiff grey chalk in the Channel Tunnel,[1] and by machinery analogous to that he had long used for converting it into slip for brickmaking purposes. From the description given, he thought it possible that Mr. Crampton's method would be applicable to the hard soapy material referred to by the Author.

Mr. Thomas. Mr. J. LEE THOMAS said it was difficult to criticise the working of a mineral deposit, such as that described in the Paper, without a complete knowledge of the contour of the surrounding country; but, provided the levels admitted of it, he had no hesitation in saying that, in his opinion, the most economical method of working the deposit in question was by sinking a shaft in the most suitable rock, whether in the rock adjacent to the deposit or in the deposit itself, and sending all the stuff broken downwards, and bringing it out to the surface through an adit or tunnel of convenient length driven in from a lower level to intersect the shaft, instead of, in a country in which all kinds of fuel were so abnormally dear, hauling it upwards by steam power. Such an adit would also serve to drain the workings, and do away with the necessity of pumping. Of course simplicity of working must be to some extent interfered with by the numerous claims into which the mine was divided.

[1] Institution of Mechanical Engineers. Proceedings, 1882, p. 440. "On an automatic hydraulic system for excavating the Channel Tunnel."

Mr. J. N. PAXMAN, in reply, observed that the geological statements in the Paper had been made on the authority of Mr. Lee, the Chairman of the Kimberley Mining Board. The system of ropeways was not one that Mr. Paxman had himself introduced or recommended; but one that he had found at work. He was anxious that some action should be taken in co-operation with the owners of the mines and the best authorities in England, with the view of improving them. Nearly £1,000,000 had been spent to clear away the reef which had fallen into the mine before the last slip that took place a month ago. The exact sum spent to pull out the shale, to February last, had been £995,595 17*s.* 5*d.*, and considering that £1,500,000 tons additional had slipped into the mine, there was ample work for engineers to do. There was still a large amount of illicit traffic going on. Nearly £5,000,000 worth of diamonds were taken out of various mines in a year; but less than £2,000,000 went into the hands of the rightful owners. He hoped that the stringent law recently passed would have the effect of stopping the illicit traffic. At present the Kimberley mines were under a heavy cloud; but he had no doubt that it would pass away, and that a prosperous future was in store. The treatment of the "Blue" was a very important matter. It was now at a great expense spread out on a large floor, 4 or 6 inches thick. It had to be carried by labour which was very dear, and spread out, and watered at a very great cost. It lay a month or six weeks to slack, and then it had to be lifted up again into a vehicle and taken to a machine to be washed. It was an expensive process, and any method that could be adopted for treating the "Blue" as soon as it was hauled from the mine and passed into the washing machine, so that it could be crushed and pulverized in such a manner as not to injure the diamonds, would confer an immense benefit on the owners. He believed that in no part of Kimberley mine was the shale of greater depth than 220 feet, and it must be borne in mind that beyond the depth of 420 feet, to which the mine was worked, it had been bored to a further depth of 200 feet with a favourable result, and every indication of the continuance of diamonds. No shale had been found in or below the seamy or hard rock. The statement of the cost of sinking the shaft was on the authority of a gentleman largely interested in this mine, but the sum mentioned was below that given to him. At the time of his visit the mine at Kamfer's Dam was being worked at the deepest, about 25 feet below the surface, with horses which pulled the "Yellow" up an inclined road cut into it. The tubs upon the aerial-ropeways ran

Mr. Paxman.

Mr. Paxman. smoothly and well when provided with good wheels, carriages and axles. A few rudely-made ones were still working, and the question was not how they ran off the wires, but rather how they kept on for a single journey. With reference to the suggestion of sinking a shaft 60 feet and working out the gallery, and then going on another 60 feet, Mr. Willcocks seemed to have lost sight of the fact that the "Yellow" extended below the distance above named, and that the shaft must be sunk sufficiently deep to pierce the "Blue." Shaft-sinking, if judiciously done, could in some cases be used with considerable advantage. The water, after being used, had a slightly soapy nature, but the chief feature was its greater gravity. When breakages in the machinery occurred it was not for the want of soapy water, but because the mill had been allowed to stand still. The diamantiferous soil which settled at the bottom then became indurated, and the force required to pass the agitator through was thus very great. No person, however well acquainted with the work, would attempt to start the mill when in this condition. The theory of the turning on of clear water stopping the machinery was to the Author quite new; certainly no stoppage occurred in practice. He was indebted to Mr. Murray for the description and history of the discovery of the diamonds, and begged further to acknowledge the assistance rendered him by Mr. W. Westhofen, Assoc. M. Inst. C.E.

Correspondence.

Mr. Appleby. Mr. C. J. Appleby took especial interest in the Paper, because he had made the first engines sent to the Diamond Fields, and had designed the standing gear, which, so far as he could learn, had not been altered in any way. With respect to the engines, the Author appeared to think there was an absence of knowledge as to the type of engine best adapted for the Fields. This, however, was incorrect. The conditions were well understood and appreciated so far back as 1875, when the first three engines were sent out; but they had to be shipped in three weeks after the order was given, so there was no time for making the special type of machinery which the Author very properly advocated. Many engines were subsequently sent, but miners were proverbially conservative on the question of machinery, and in every case they ordered engines exactly like those previously dispatched. The great advantage of the double-standing wire-ropes was, that they were much safer and more durable than the single ropes used

prior to 1875, when he was consulted on the subject, and of course the two ropes need not be strained so tight as the single rope.

Prof. Green.

Professor A. H. GREEN supplied some notes in illustration of the geological conditions under which the diamonds occurred. Fig. 4 was a generalised sketch section of the Kimberley diamond mines. The surface of the country was very generally covered by red sand and sheets of calcareous tufa; these were purely superficial, and were now in the course of formation. They were found not only over the diamond-bearing pipes, but were spread over nearly all the country. Beneath these superficial matters the rock for many miles round Kimberley was shale traversed by a large number of dykes and intrusive sheets of trap. He had not yet examined the specimens in his possession, so he could not say for certain what the trap was, but very likely it was a dolerite. The

FIG. 4.

Red Sand and Calcareous Tufa.

Pipe of Diamond-bearing Breccia.

diamond-bearing stuff occurred in great pipes, rudely cylindrical in shape, running down vertically through the shale and its associated trap sheets. Sometimes, as at Kimberley, shale occurred at the top, and a trap sheet was reached some way down; sometimes, as at De Beer's, there was a trap sheet at the top and shale below. The diamond-bearing stuff was a breccia or agglomerate, and from the way in which it occurred, it presumably filled in the funnels or throats of old volcanoes. The material in the upper part of the pipe was generally distinguished as "Yellow Ground," that lower down as "Blue Ground"; but there was no difference between the two; the stuff was blue where it was deep enough to be protected from the action of the air, nearer the surface the iron had become hydrated, and this had changed the colour to yellow. Exactly the same change occurred in the shale. He noted one mistake of the Author, where he said, "The next stratum, varying in depth from 60 to 100 feet, is of the nature of a loose yellow gravelly lime." The Author was here mixing up the superficial

Prof. Green. coating of calcareous tufa and the "Yellow Ground"; the tufa often found its way down for some distance along cracks in the "Yellow Ground," but the two were perfectly distinct, and the tufa was never more than a few feet thick.

In pursuance of the notice on the card of the meetings, it was resolved to adjourn for a fortnight, in order to avoid the holding of a meeting on Whitsun Tuesday, May 15th.

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22 May, 1883.

JAMES BRUNLEES, F.R.S.E., President, in the Chair.

(*Paper No. 1926.*)

"The Edinburgh Waterworks."[1]

By ALEXANDER LESLIE, M. Inst. C.E., F.R.S.E.

THE water-supply of the city of Edinburgh is derived from two main sources in almost equal portions, namely, the Pentland Hills and the Moorfoot Hills. Previous to the introduction of these supplies, the inhabitants depended entirely on wells situated within the city. Authenticated accounts of the water-supply to Edinburgh date as far back as 1621, when steps were taken for the introduction of the first gravitation supply. An Act was passed by the Scottish Parliament in that year for the introduction of water from the Comiston springs, which rise about 3 miles to the south of Edinburgh; but it was not until 1681 that the water was actually brought into the city. The supply amounted to about 135,000 gallons per day, and was carried by a 3-inch lead pipe, at a cost of about £3,000. About twenty years later additional springs were brought in from near the same source, and a lead pipe 4½ inches in diameter was substituted. The design of this work is attributed to Desaguliers, and it was executed by a German of the name of Covay; but it was not until 1720 that the inauguration of the work took place. No further addition to the supply was made until thirty-five years later, when, after a time of great scarcity, an additional volume was obtained from Bonaly, 6 miles from Edinburgh, and other streams and springs on the north side of the Pentland Hills were brought by way of Swanston, and this supply was introduced in 1761. It was conveyed into the town by wooden pipes, which were mostly removed and iron pipes substituted in 1790.

In 1780 a report was obtained from John Smeaton upon the then existing supply. He made several suggestions, but did not

[1] The discussion upon this Paper was taken together with that upon the two following ones.

submit any proposals of importance for securing additional quantities from other sources.

The next report of moment was by Telford in 1811. In this he states that an improved supply might be obtained from springs situated on the eastern portion of the great Pentland range of hills.

Previous to the introduction of the Moorfoot water, the whole of the supply was derived from the Pentlands, a range of hills, about 16 miles long and 5 miles wide, lying to the south-west of the city. They are of irregular outline, and their highest summits vary from 1,000 to 1,900 feet above the sea, while the general level of the plain from which they spring rises gradually from 500 feet at the north-east end to about 900 feet at the south-west. According to the memoirs of the Geological Survey, these hills consist fundamentally of highly-inclined upper Silurian strata, and grits covered conformably by coarse conglomerate grit and sandstone, and great sheets of felstone and ash belonging to the upper Old Red Sandstone group. These rocks, with very varying outlines, form an anticlinal axis, over which the Carboniferous rocks are folded, though, owing to large parallel faults, the regularity of this anticlinal has been materially disturbed, and it is to the existence of these faults that most of the copious yield of spring water, which forms the bulk of the supply from this source, is due. The country on the east of the hills consists entirely of Carboniferous strata, extending southwards until they abut against the Lower Silurian formation of the Moorfoots and Peebleshire hills, which form the watershed of the new supply known as the "Moorfoot Water Works." A long line of fault runs along the south-east flank of the Pentland range, which has the effect of bringing down the Carboniferous series against the edge of the strata of the felstone rocks, which, as they dip in that direction, cause the water percolating through their open fissures to rise to the surface whenever they come in contact with the closer material of the more recent formation. Thus large numbers of springs rise along the whole line in which this fault can be traced. Some of them, namely, the Crawley springs, form part of the supply of Edinburgh, while many others are utilized for the supply of neighbouring towns and villages, or are appropriated for the use of the paper manufactories on the North Esk river, into which they naturally drain.

The springs on the north side of the range are also doubtless, in a great measure, to be attributed to the existence of similar faults; but as there is a greater accumulation of *débris* near where they rise, it is not so easy to trace the lines of the faults on this side.

The springs, with the exception of those rising on the north side of the Blackhill, are remarkably steady. The Appendix contains a tabular statement of their average yield for the last twenty years.

The Edinburgh Water Company was formed in 1819, after the town had experienced a very great scarcity of water. The then existing works were acquired from the Corporation, for which they were paid, in stock, £30,000. In that year the new Company applied to Parliament for powers to introduce the water of the Crawley springs and part of the Logan burn in the Glencorse valley, which scheme had formed the subject of the report by Telford. These works were designed by Telford, and the original plans bear also the name of John Rennie, who acted as Engineer in the interests of the landowners affected by the scheme, and they were carried out under the superintendence of Mr. Jardine, the Company's Engineer. The water was introduced into Edinburgh in 1822, at a cost of £229,000, the increased supply amounting to about 2,700,000 gallons per day.

The works consisted in collecting the various springs rising in Crawley Haugh, a Table of the yield of which is given in the Appendix, from which it will be seen that the supply is comparatively steady. These springs are led by a masonry culvert into an equalising tank within a short distance from where they rise, and by means of another culvert a portion of the surface water from the Glencorse valley is added to it.

The water of the Crawley springs naturally formed part of the drainage of the North Esk valley, into which they flowed as part of the Glencorse burn; and as, upon the North Esk, are situated numerous manufactories, chiefly paper-mills, it was necessary to provide compensation before permission could be obtained to divert, for the supply of Edinburgh, the water which otherwise would have flowed down the North Esk. An eligible site for a large reservoir existed about 1 mile beyond the Crawley springs, in the Glencorse valley, and there what was originally known as the compensation pond was constructed (Plate 2 and Plate 3, Figs. 1, 2, 3, 4). It covered about 50 acres, had a maximum depth of 58 feet, and a capacity of about 300,000,000 gallons. The water was drawn off from the bottom of the reservoir by an arrangement of culverts and cast-iron pipes, which were laid on the solid ground, but without any sluice-valves at the inner end. These valves, however, were placed on the pipe immediately to the outside of the puddle wall or trench, where the pipes enter an elliptically-shaped culvert of masonry, through which they are carried till they reach

the tail of the embankment. Here, by means of an arrangement of flap-valves, the water can be turned into a large cast-iron tank, and the amount of its discharge be ascertained.

The experience of the last sixty years shows this arrangement, although perhaps safe enough, to be very inconvenient, as any alterations on the opening of the sluices can only be effected by going up this rather confined culvert to reach them.

There is an upper outlet, or safety tunnel (Fig. 4), at a level of about 18 feet below the original surface of the reservoir, for the rapid discharge of floods. The inner end of this was fitted with a heavy iron casing containing two sluice-shuttles lying at an inclination of about 1½ to 1, each opening being 6 feet by 2 feet 6 inches, worked from the top by gearing connected with the shuttles by rods lying on the face of the bank. The inner portion of this culvert is circular, 4 feet in diameter. This circular portion extends for a distance of about 300 feet, after which it widens out to the dimensions of 6½ feet by 4½ feet, with a semicircular roof and vertical walls.

The crest of the waste weir is 60 feet in length, and the channel from it, after a slight fall, is almost level. The nature of the ground renders it possible to allow the surplus water from the reservoir to drop over the end of the channel, where, in floods, it forms a cascade about 80 feet in height, the rock over which it pours being sufficiently strong to stand without the slightest protection.

The embankment was carefully put together with a watertight heart of puddle, and no accident is reported to have occurred during its construction, although considerable excitement and alarm were caused by the accumulated waters of a flood which nearly overtopped, and was likely to wash away, the half-constructed embankment; but provision was made to prevent this by temporarily spreading tarpaulings or other sheets over the soft material of the bank.

One peculiar feature in this scheme consisted in the construction of the "filter-tunnel," a culvert about 20 feet under the surface of the valley, into which the water flowing in the burn was intended to percolate, and so far purify itself; but from the loamy nature of the material it turned out not to be very efficient. It was this water which, after being mixed with the yield of the Crawley springs in the Crawley water-house, formed the new supply introduced in 1822, when it was confidently hoped that there would be no further want of water for Edinburgh for an indefinite period.

The pipe which conducted the water to the city had necessarily to take a circuitous course, and is 8½ miles long, while the direct

distance by road is little more than 6 miles. The pipe is of various diameters, commencing with a flat gradient at 20 inches diameter, and being partly 18 inches, and the bulk of the remainder 15 inches. This pipe has stood remarkably well. About fifteen years ago it was necessary to open it, and the interior was found free from incrustation.

The Act of 1819 provided that compensation was to be given to the millowners on the North Esk, at the rate of 200 cubic feet of water per minute from November to April inclusive, and at the rate of 180 cubic feet per minute from May to October.

This additional supply was only found to be sufficient until the year 1836, by which time the consumption of water had so greatly increased, that it had the effect of entirely emptying the large Glencorse reservoir. This was a most serious affair, inasmuch as by the Act the Company was bound, in the event of their not being able to discharge the requisite compensation into the stream, to stop the spring-water supply to Edinburgh, and send it down the Esk in place of the compensation from Glencorse reservoir. However, the springs were reserved for Edinburgh at the cost of the shareholders of the Company.

In 1843 another Act was obtained for the introduction of additional water, namely, the Bavelaw, Listonshiels and Black springs, which lie on the north side of the Pentlands, and this work was completed in 1848, at a cost of about £100,000, the amount of the supply being about 2,000,000 gallons per day. The manner of providing compensation in this case differed from that at Glencorse, and the same principle has been adopted on subsequent occasions of a similar nature.

The promoters were held bound to construct compensation reservoirs calculated to contain a volume of water equal to eight months' yield of the springs, as determined by gaugings during the eight months from March to October inclusive, of two consecutive years. The reservoirs, having once been filled and handed over to the representatives of the millowners, all responsibility regarding them, except as to their maintenance, terminated as far as the Company were concerned; and the millowners have power to order the water to be discharged in whatever daily quantities they consider best.

The compensation-reservoirs which were constructed in connection with this scheme were two in number, namely, Threipmuir and Harlaw. Threipmuir covers an area of about 134 acres, with a maximum depth of 23 feet, and contains about 206,000,000 gallons. The embankment is 960 feet long, and is of substantial

dimensions, having the top 8 feet in width and 7 feet above the top water of the reservoir, with an inside slope of 4 to 1, and an outside slope of 2½ to 1. There are two outlets from this reservoir, one outlet being 7 feet above the level of the other. They both consist of cast-iron pipes 2 feet in diameter, and their upstands are composed of oak, erected on the inner end of the pipes, by means of which access is obtained to the sluice-rods.

The water from this reservoir, which is formed upon the Bavelaw burn, a tributary of the Water of Leith, into which the springs obtained under this scheme naturally flowed, passes into the lower, or Harlaw reservoir, which has a surface area of about 34 acres, a maximum depth of 64 feet, contains about 169,000,000 gallons, and has an embankment 387 feet in length. This reservoir also has two outlets, consisting of cast-iron pipes, the upper one laid 40 feet above the bottom. At the inner end of each pipe is an upstand shaft of 7-feet internal diameter. Gangways supported on timber piers lead out to the two upstands. The sluice-wells, or shafts, are each furnished with an outer sluice of oak, working in guides, each extending the whole height of the tower; so that the sluice may be drawn up to the surface when the reservoir is full, if required for repair; and there is also a valve inside the shaft, on the inner end of the pipe which is laid through the embankment.

Shortly before the completion of this reservoir, the inside slope of the embankment showed signs of slipping, in consequence of its having been put together rather too hurriedly, without sufficient attention to the fact of its being composed entirely of hard boulder clay, which it is difficult so consolidate without excessive wetting. This had the effect of slightly displacing the masonry of the tower; but it has stood for more than thirty-five years without further signs of movement. The waste-weir of the reservoir is 100 feet long, and the drainage area about 3,934 acres; while that of Threipmuir is about 3,613 acres, and the length of the waste-weir 90 feet.

Another Act was obtained in 1847, which gave powers to construct four additional reservoirs, and to increase the capacity of the Glencorse reservoir; the storage originally provided there having proved inadequate to utilize nearly the whole waters of the Glencorse valley. Provision was made for increasing its capacity by raising the water-level 4 feet, and also for constructing in the upper part of the same valley the Loganlea reservoir; so that now there is an available storage in Glencorse valley of about 480,000,000 gallons. To utilize the yield of the district of about

3,428 acres, and assuming 20 inches depth as the available rainfall, there is not more than four months' storage of this yield; so that, as has indeed been proved by the amount of waste passing over the weir, there is still a considerable volume of water not utilized. By this Act the amount of compensation water was altered to 220 cubic feet per minute continuously.

Power was also obtained to construct Clubbie Dean, Torduff, and Bonaly reservoirs, upon the north side of the Pentlands, the two former being intended to store the surplus water of the springs of winter for use during the dry months of summer. This scheme was laid out by the late Messrs. Rendel and Beardmore, MM. Inst. C.E., and the working plans were made and the works carried out under the superintendence of Mr. James Leslie, M. Inst. C.E., who, on the resignation of Mr. Jardine in 1846, was appointed Engineer to the Edinburgh Water Company.

The Clubbie Dean, Torduff, and Loganlea reservoirs are much alike, and a description of one will suffice for all. The embankments were formed with slopes of 3 to 1 inside and 2½ to 1 outside, with a width of 10 feet on the top, which was 5 feet above top-water-level; a puddle-wall in the interior of the bank, 8 feet wide at the top, increased with a batter of 1 in 8 on each side down to the level of the ground, the depth of the puddle-trench varying according to the nature of the material. The body of the embankment was formed of layers not exceeding 6 inches in thickness, carefully put together. This is doubtless a much more satisfactory manner of constructing embankments than is customary in many other places, and it cannot be denied that it has its advantages, one of the most important being, that should the embankment happen to be breached, so as to allow the water to escape over the top, the danger of the whole giving way is much less than where a reservoir-embankment is put together in layers of from 4 to 6 feet in depth. Another objection to high tips is that the bank naturally forms into a series of open layers as the large material invariably falls to the bottom of the slope, while the finer material remains above, and this principle is repeated from time to time as the bank increases in height.

The Loganlea and Torduff reservoirs have each a tunnel driven in the solid rock (Fig. 5), through which the water from the lower outlet is led, while there is an upper pipe at a level of about 30 feet below the surface, for enabling the water to be drawn off as near the surface as possible, thereby ensuring greater purity and avoiding unnecessary strain in working the valves under high pressure.

The Clubbie Dean reservoir has only one outlet-pipe, 21 inches in diameter, and it is fixed together by bolts passing through lugs cast on the outside of the ordinary spigot and faucet.

The aqueduct conveying the spring-water from Bavelaw and Listonshiels is laid along the north side of this reservoir. It is partly of brickwork and partly of masonry 3 feet high and 2 feet wide. It crosses the ravine of the Bavelaw burn, along the outside slope of the Harlaw reservoir, in a cast-iron pipe; this pipe again enters a built conduit, and is led eastwards towards Clubbie Dean reservoir, into which it can either be discharged or taken past in pipes. There is a measuring cistern, at the lower side of Clubbie Dean embankment, by which the yield of the springs can be ascertained, and from this point, about 700 feet above Ordnance datum, one of the pipes supplying the North Pentland water is led direct to Edinburgh.

A similar cistern is erected near the Torduff embankment, into which is discharged the surplus spring water from the Clubbie Dean pipe, and also the water from Torduff which percolates through filter-beds in the immediate vicinity. From this measuring cistern, at 550 feet above sea-level, a second pipe conveys the water to another district in Edinburgh. These works were all completed about the year 1851.

The increased demands of the public again rendered it necessary to apply to Parliament for additional powers, and an Act was obtained in 1856 authorising the introduction of the Colzium springs. These springs were collected in a similar manner to those before alluded to, and were led to join the already existing aqueduct at Westrig cistern, the aqueduct having originally been made of sufficient capacity to carry them, and also other springs, to be subsequently appropriated further west.

A compensation-reservoir was also constructed on the Water of Leith, at Harperrig, for the purpose of compensating the mill-owners on that stream, and the works were completed and the springs introduced in the summer of 1859. Harperrig reservoir has an area of about 174 acres, and a maximum depth of 38 feet, and contains about 562,500,000 gallons. It is situated in a most favourable position as far as the relative size of the reservoir and embankment are concerned. Few reservoirs have such a small embankment in proportion to the amount of their contents (Fig. 6). The outlet for compensation-water is by means of a culvert sufficiently large to permit of the passage of floods during the construction of the reservoir from an area of about 4,217 acres. The culvert is of ashlar, 6 feet wide by 7½ feet high, with semi-

circular roof. The upstand-shaft at the inner end of the culvert is square, and furnished with sluices outside and inside. The waste-weir is 100 feet long on the crest, being at the rate of 1 foot for every 42 acres. Besides the compensation given for mill-power, which was calculated in the same manner as in the case of Threipmuir and Harlaw reservoirs, there was an additional tax on the resources of the Company, by the paper-makers and bleachers on the Water of Leith obtaining a supply of pure spring-water from the pipes of the Company amounting to about 400,000 gallons per day. This was on account of deterioration in the quality of the water left in the Water of Leith owing to the abstraction of the springs, and the increased proportion of mossy water which resulted therefrom. The addition from this source was about 2,000,000 gallons per day.

A still further supply was obtained from the Crosswood springs, an Act for which was passed in 1863, and this water was introduced in the year 1868, and a reservoir was, as usual, constructed on the Crosswood burn to compensate the millowners.

Crosswood reservoir has an area of about 62 acres, with a maximum depth of 40 feet, and is constructed, as regards its outlet works, in a manner similar to that at Harperrig; but the waste-weir and channel are somewhat different, owing to the greater length of the Crosswood embankment, which, after crossing a gorge of about 200 feet in width, is continued in a curve for a distance of 1,200 feet. It was necessary to construct an overflow-weir near the deepest part of this bank (Fig. 7). For this purpose a wall of masonry has been brought up, faced on the outside with ashlar-steps having a slope of 1½ to 1, the rise of each step being 16 inches and the tread 24 inches; the top of this forms the crest of the weir over which the flood-water escapes. The weir-channel, with a flat gradient, is led in the ordinary manner from the bottom of this flight of by-wash steps.

The supply from the Pentland works is so far peculiar as it consists almost entirely of spring-water. This peculiarity is of great importance, inasmuch as large expensive storage-reservoirs, such as are to be found in many other places, have been thereby rendered unnecessary, and although the springs of course may get low in dry weather, no absolute want of water can ever be experienced. Indeed the configuration of the north side of the Pentlands would not permit of a surface-water scheme being adopted for Edinburgh, as that water is almost always coloured with peat, and in wet weather very much so. This remark does not apply to the Glencorse valley, as the springs could still be made avail-

able for compensation purposes in the event of the available discharge running low, although the more recent increased storage in that valley renders such a contingency extremely unlikely. The water draining into Glencorse is naturally free from peat, the watershed consisting of high hills, covered with short grass. However, it becomes more mossy towards the upper reaches, so that the water impounded in Loganlea is at times dark coloured; but owing to the existence of a spring which rises in the downstream side of the puddle-trench, and which has some remote connection with the water inside the reservoir, and which passes through the rock and is discharged bright and clear in large quantity, it is but seldom that much water requires to be sent down by means of the sluice itself.

This completes the history of the Waterworks of the Edinburgh Water Company, which were capable of producing about 8,000,000 gallons per day. In 1868 this volume was estimated to be equal to about 34 gallons per head per day to a population of 230,000, about 14 per cent. of the quantity being used for manufacturing purposes. The cost of the works up to that time had amounted to £500,000.

In 1869 an Act was passed for taking over the works of the Water Company and investing them in a public trust consisting of representatives of Edinburgh, Leith, and Portobello, and they came into power at Whit-Sunday of the following year. The first proceedings of this Trust consisted in an application to Parliament for power to introduce the water of St. Mary's Loch, which Bill, after having passed the House of Commons, was rejected by the House of Lords.

It was ultimately decided, in deference to the wishes of the ratepayers, to adopt the Moorfoot or South Esk scheme, which had many years before been recommended to the old Water Company by their Engineer, and had also been shortly before reported on favourably by Messrs. T. Hawksley and J. Leslie, MM. Inst. C.E., jointly.

Moorfoot Scheme.

Plans were lodged for this Bill in the autumn of 1873, and Parliamentary sanction was obtained for it in the following session.

The watershed under this scheme consists of the Moorfoot hills, which form portions of the long band of Silurian uplands stretching across Scotland from St. Abb's Head on the east to Portpatrick on the west. These hills are rounded on the sides, and covered with green pasture, while the tops are flat and have

peat on some portions of their summits. There are not many springs in this district. Around the base of this Silurian range is found the other extremity of the Carboniferous strata mentioned before as lying between them and the base of the south side of the Pentlands. It was anticipated that a higher rainfall would have been available here than in the Pentlands, but the Tables in the Appendix show that this expectation has not been realised.

The Moorfoot scheme consists of the utilization of a drainage-area amounting in all to about 14,500 acres. Of this about 6,131 acres form the portion of the watershed of the Gladhouse burn above the site of the reservoir of that name; about 1,337 acres form the available drainage area of the Tweeddale burn, and these, together with the Portmore Loch, with its drainage area of some 610 acres, form the portion available for town supply. The scheme was laid out upon the assumption that compensation should be provided in the proportion of one-third of the yield of the district operated on, leaving two-thirds of the yield for town supply; and reservoirs have been provided having storage equal to six months' yield of the districts.

The available rainfall of the Portmore district was estimated at 24 inches, after deducting for loss by absorption and evaporation from the actual rainfall of 38 inches, while the Tweeddale burn drainage-area and that of Gladhouse reservoir was estimated at the smaller quantity of 20 inches.

To utilize the yield of these districts the Gladhouse reservoir has been constructed upon the river "South Esk," or Gladhouse burn, which is calculated to store six months' yield of its own drainage-area, reckoned at the above-mentioned amount, along with the flood waters of the Tweeddale burn drainage-area and the area lying between it and Gladhouse reservoir. Its capacity is about 1,700,000,000 gallons. The Portmore reservoir, constructed on the site of the existing loch or lake, has a capacity of about 250,000,000 gallons. This is more than in ordinary circumstances would have been considered a necessary amount of storage, but on account of the nature of the locality and the cheapness of the necessary works, the storage was increased from six months' to ten months'. The scheme also includes the construction of the Rosebery reservoir upon the South Esk, 2 miles below the Gladhouse reservoir, whereby about 1,620 additional acres are utilized, by means of which, as their yield is entirely devoted to compensation purposes, the total yield of the South Esk or Gladhouse burn, above the site of the Gladhouse reservoir, is rendered available for town-supply.

To compensate for the utilization of the waters of the Tweeddale burn and the Portmore district, the Edgelaw reservoir has been constructed on the Fullarton burn, and the total amount available from the Moorfoot sources for the supply of Edinburgh is estimated at about 8,690,000 gallons per day.

During the passage of the Bill through Parliament, a serious draught was made upon the resources of the scheme, inasmuch as the riparian landowners had demanded a volume of water *gratis*, for domestic and manufacturing purposes, amounting to about 750,000 gallons per day, to be delivered by pipe at their respective properties, and this demand was conceded to them rather than risk their opposition.

Before proceeding to describe the Moorfoot works in detail, it may be well to complete the account of the subsequent Parliamentary proceedings in connection with them. In the Bill of 1873–74, it was not intended to apply for power to construct the Rosebery reservoir, because, several years before, power to construct a reservoir upon that site had been obtained from Parliament by the local authority of the town of Musselburgh, for the supply of that town and also the neighbouring town of Dalkeith; and, in consequence of apprehension lest the Bill should be endangered by the opposition of these parties, this reservoir was omitted. To make up for the want of this reservoir, the capacity of the compensation-reservoir to be constructed upon the Fullarton burn was therefore increased, with the intention of serving for both the compensation due to the South Esk proper and its tributary the Fullarton burn; but, at the instance of the advisers of the landowners, the contents of the Edgelaw reservoir were reduced from 800,000,000 to 275,000,000 gallons, and the compensation, which it was intended to obtain from the Edgelaw reservoir, had, instead, to be taken from the Gladhouse reservoir, thereby diminishing the volume available for Edinburgh without, in the opinion of the engineers, benefiting the proprietors, inasmuch as no water-power was available on the course of the Fullarton burn, nor on the South Esk above the point of junction of the two streams, so that it did not signify from which source compensation was obtained. In order, therefore, to render available for the supply of Edinburgh the whole volume of water previously mentioned, it became necessary to have recourse to the reservoir formerly contemplated at Rosebery, and this was subsequently done.

The Edgelaw reservoir was intended to be 90 feet deep, covering an area of 104½ acres, and the works would have been materially

reduced in extent in carrying out the provisions of the Act of Parliament, by which the contents were to be so much diminished. While trial-boring operations were being prosecuted, to test the nature of the foundation for the puddle-trench, what on a previous occasion had been taken for solid rock turned out to be merely a boulder, although the bed of the stream and its left bank consisted of sound rock. A pit was accordingly sunk in the immediate vicinity of the original bore-hole, but no firm bottom was reached at the level previously indicated. After proceeding further with this pit, which was entirely through fine sand, and required careful timbering, it was at length abandoned and the original bore-hole continued. The boulder was soon pierced, and the boring-rods went down to an additional depth of nearly 30 feet without reaching solid rock. It was, therefore, considered advisable to look out for another site, so that the embankment might be constructed in a more economical manner. A careful examination into the geological structure of the valley showed that the site of the before-mentioned bore was in the channel of a pre-glacial watercourse. The whole surface of the country having undergone complete alteration, during the period of the ice age, by the levelling up of the valleys and watercourses with sand and *débris*, the existing river-bed has been excavated in a different line from the original one, and has not yet attained nearly so great a depth. Further investigation of the valley of the Fullarton burn shows that the present and the former beds of this same stream frequently interlace, and it is difficult to fix upon any part of the river-course without the risk of encountering sand-beds of considerable depth either at one side or the other. Fortunately, however, a site was found about 1 mile further down the stream, sufficiently far removed from the original course, which in all probability is filled with sand and other pervious material, and this second selected site is so situated as to form a most economical site for a reservoir embankment. It is in the carboniferous formation, and various seams of coal and shale were met with in the excavations of the works.

Application was made to Parliament in the session of 1875–76 for power to abandon the original Edgelaw reservoir and to construct another one upon this new site; and, the powers of the Musselburgh and Dalkeith Water Act having lapsed, the opportunity was taken to include the construction of the Rosebery reservoir, thereby giving an increase in the available supply for Edinburgh of 2,500,000 gallons.

To finish the history of the Parliamentary proceedings in con-

nection with the Edinburgh water supply, it may be mentioned that, by the plans lodged in 1874, it was intended to construct a reservoir and filters in a convenient position at Alnwickhill; but that, in consequence of the opposition of the agents of the proprietor, it was necessary to restrict the area of the works, so as to interfere materially with their design. The Trustees were, however, assured that additional land elsewhere would, if necessary, be granted for carrying out the works, even though beyond the limits of their compulsory powers. Relying on this promise the works were commenced; but the tenant of the ground, not having been made a party to the bargain, interrupted the progress of the works by obtaining an interdict from the Court of Session, on the plea that the ground included within the limits of deviation under which the land was acquired by the trustees, was intended to have been utilized for the construction of a pipe-track instead of forming a portion of the embankment of a reservoir. It is difficult to see how the tenant of a piece of land such as this, after having had it taken from him, and after having been paid and compensated for his loss, could have any right to complain of the use to which the land was being put. The Court, however, held that he was entitled to object, and his opposition had, in consequence, to be bought up at a considerable ransom. The question is by no means a new one, and has occurred on several occasions; but, as far as the Author is aware, the decisions have generally been in favour of the promoters of the scheme. The result of this interdict was, that a third application to Parliament was rendered necessary in 1877, to obtain powers for the construction of the works on the land which the proprietor had promised to provide during the passing of the previous Act of 1874.

A fourth Act was obtained in 1880 for increasing the borrowing powers of the trustees, which by this time had become nearly exhausted, but no additional works were sanctioned under it.

The original Act included the construction of a reservoir in the Glencorse valley to be called Denscleuch, intended to have a capacity of 260,000,000 gallons, for the purpose of utilizing more fully the yield of that district, which, as before mentioned, is by no means thoroughly exhausted, but it was ultimately decided to abandon it.

Gladhouse Reservoir.

The first of the works contracted for was that of the Gladhouse reservoir. It has an area of about 396 acres, and is formed by an embankment across the Gladhouse burn about 1000 feet in length.

The maximum depth of water in the reservoir is 68½ feet. The embankment has a width at the top of 12 feet, which is 7 feet above the top-water level of the water in the reservoir. The embankment was constructed in the manner before described (Fig. 9). The nature of the rock foundation was such that only a remarkably shallow puddle-trench was required, not exceeding 3 feet in depth below the bottom of the valley. Even in those portions which were deepest from the surface, but which did not in any place exceed 20 feet, the trench was remarkably free from water, so that the expense of pumping, which in many other reservoirs has been very considerable, was avoided. This is, perhaps, all the more worthy of notice, as it not unfrequently happens in the execution of puddle-trenches that the fact of their being dry and free from water, is an indication of their inefficiency to prevent the passage of water.

The water available for town-supply is drawn from the reservoir through a pipe placed at the level of 25 feet above the bottom, while it and the compensation outlets are connected with an upstand shaft inside the embankment 140 feet from the centre line thereof. This tower or shaft (Fig. 9) is constructed of parapet ashlar 2 feet in thickness on the bed. The tower measures 18 feet by 10 feet externally, and is divided into two chambers, one of which communicates solely with the compensation outlet in the bottom, and the other, in addition to a similar communication, contains the sluices on the mouth of the supply-pipe. There are two sets of double-sluice at the level of the bottom of the reservoir for the compensation water, one set in each chamber, and there are three outside sluices, which communicate with the town-supply, fixed at different levels so as to permit of the clearest water, which is the nearest the surface, being drawn off for consumption.

The upstand was constructed with a clear passage below it formed by arches, on which the superstructure was built, so as to allow the flood-water to pass uninterrupted during the construction of the works; after the completion of the embankment these arches were filled up with solid masonry. The outlet-pipe, 27 inches in diameter, delivers into a measuring-cistern situated at the outside of the embankment. This pipe was carefully bedded in solid rock, and encased with a thick layer of lime concrete, and it was terminated at the lower end with a turn-down pipe which discharges into a small chamber, by means of which the velocity of the water is checked and its correct measurement facilitated. This measuring-cistern also receives in a similar chamber another

turn-down pipe, which conveys the water from Portmore Loch, and, if necessary, Tweeddale burn, and these together, as well as the water from Gladhouse, can be at any time accurately measured by an arrangement of cast-iron troughs and flap-valves, which permit of the water from either source being measured in the body of the cistern by observing the rate of rise of the water.

From this cistern or measuring-house is led the main conduit to Edinburgh. According to the original design it was intended, for the purpose of economy, to provide for the passage of the flood-water, during the construction of the embankment, by a tunnel calculated to be of sufficient cross-sectional area to discharge the largest probable flood. After the works should be finished, of course the excessive size of the outlet-culvert was no longer required; it was therefore intended to diminish its area by building a masonry culvert inside to carry the compensation-water. The material, however, through which this tunnel was driven proved to be by no means so suitable for the purpose as had been anticipated, and partly owing to this, and to the unskilful manner in which the operations of mining were conducted, this scheme had to be abandoned, and the intended tunnel was open-cut from end to end. The stability of the work was by this considerably increased, and, except as regards the matter of expense, was in nowise to be regretted.

Instead of the original design, which consisted of ashlar masonry, a culvert of brickwork was substituted, with curved walls and segmental arch, the brickwork consisting of six rings, and it is packed behind close up to the rock face with concrete (Fig. 10). The crest of the weir is formed of an ashlar curb 18 inches by 2 feet deep, laid in a curve at a radius of 130 feet, as shown in Fig. 8.

The works for this reservoir cost £58,000, and the land purchased for it contained 400 acres, for which the sum of £41,000 was paid, the proprietors being the Earl of Rosebery on the west or left side, and Mr. Dundas of Arniston on the east or right side of Gladhouse burn. The contractor for the reservoir works was the late Mr. William Mackenzie of Edinburgh, and the iron work, which cost £4,164, was provided by Messrs. Hanna, Donald and Wilson, of Paisley.

A second small embankment was rendered necessary near the upper end of the reservoir, which was only 200 feet in length and 14 feet in depth; but this embankment had to be sunk through 34 feet of gravel before a watertight substratum could

be reached, and much greater labour and expense were incurred in obtaining a proper foundation here than in the case of the main embankment, which contains sixty-two times as much material.

The site selected for the main embankment of this reservoir is particularly favourable, not only on account of the facility of constructing the puddle-trench, but also on account of its small size in relation to the amount of water impounded, the proportion being 2,000 to 1.

The other works in connection with this reservoir consisted of the diversion, by means of an open aqueduct, of the waters of the Blackburn, a tributary of the Gladhouse burn, which, on account of the nature of its drainage-area, is apt at times to be coloured. It has been led past the reservoir and discharges into the waste-weir channel, while there are appliances to permit of its waters being taken into the reservoir when sufficiently pure. There are also various roads, bridges, and small embankments.

PORTMORE RESERVOIR.

This reservoir was constructed on the site of a natural loch, originally about 82 acres in extent, which has been enlarged to 106 acres; the depth of water has also been increased 10 feet.

The works consist of an embankment and waste-weir and upstand and an outlet-pipe, constructed upon the same principle, though on a smaller scale, as those already described for Gladhouse. The water from this source is remarkably pure, the drainage-area being almost entirely free from peaty matter. The only mill affected by the operations of this loch above the site of the compensation-reservoir at Edgelaw, is the threshing-mill belonging to the West Loch farm-steading. Formerly this was driven by an ordinary water-wheel, but in order to economise the water for town-supply, a turbine wheel was substituted, and an available fall of 70 feet was obtained by laying a 12-inch pipe the whole way from Portmore Loch to the mill, a length of 1,000 yards. A 24-inch vitrified clay pipe conveys the water from Portmore Loch as far as Gladhouse reservoir, and discharges it into the measuring-house before mentioned.

Tweeddale burn, at a point where it is intercepted for the supply of water to Edinburgh, has a drainage area of about 1,337 acres, which is calculated to yield a daily supply of 1,500,000

gallons. A breastwork has been constructed across its course, and its waters are led into a channel of sufficient dimensions to contain it in considerable floods.

The upper end of this watercourse consists of a covered conduit measuring 3 feet 6 inches by 4 feet 9 inches, which afterwards discharges into an open water-course of concrete 15 inches in thickness, with a radius of 7 feet 3½ inches, a width of 13 feet 6 inches, and a depth of 4 feet 6 inches, surmounted with a stone coping along each side (Fig. 11). This conduit during its course receives the water from several small tributaries, including the Fumart Syke, and passes on to join the Gladhouse reservoir near the small embankment; besides which there are appliances for leading it into the fire-clay pipe conveying the water of Portmore reservoir, so that it can be taken direct to Edinburgh without entering Gladhouse reservoir.

The above-mentioned works were also constructed by Mr. William Mackenzie, and their cost was £32,659. The sum paid for the use of the water of Portmore reservoir, and as compensation, was £10,000. The way-leave for the pipe-line and the ground procured for the construction of the Tweeddale burn aqueduct was included in this sum.

Aqueduct and Pipe-Track from Gladhouse Reservoir to Alnwick Hill.

For the first 1½ mile of its course the water is led by means of a built aqueduct (Fig. 12), with a gradient of 1 in 2,000. It is 4 feet 6 inches high, 3 feet wide, and has an invert of brickwork with a radius of 5½ feet, which is set upon a foundation of concrete. The side-walls are of rubble masonry set in hydraulic mortar; the facework, consisting of composition brickwork, the bricks being each 12 inches by 6 inches by 3 inches. The arching was formed of 6-inch brickwork with a radius of 18 inches, and the whole was covered with a layer of Portland cement concrete which was intended to strengthen the arch and render it watertight. No part of this aqueduct was of excessive depth, except at one or two places where, in consequence of the impending danger of slips taking place, it was found necessary to increase the thickness of the walls and roof. Manholes were constructed at intervals of 200 yards for obtaining access to the aqueduct for repair; and where the line of the aqueduct crosses two ravines the water is led down and up again by cast-iron pipes 33 inches in diameter,

each inverted siphon, as it is called, being furnished with a cleansing-cock at its lowest extremity. This aqueduct, which is 3,000 yards in length, discharges into a circular well 12 feet in diameter and 16 feet in depth. At this point the pressure is put on the main pipe which leads to Edinburgh, and provision has been made for future extension by having two pipes built through the walls of this cistern. The pipe which leads from this cistern to Edinburgh is calculated to carry 9,000,000 gallons of water per day; the first portion of the pipe, having a flatter gradient, has been made 24 inches in diameter, while the remainder is 22 inches.

The first important work on the line of this pipe-track consists of a tunnel through rising ground 420 yards in length. The tunnel was driven through freestone rock, and was lined throughout with 9-inch brickwork forming vertical side-walls and an arched roof. The pipe was laid upon blocks of stone and kept to one side, so as to admit, if necessary, of a second pipe being laid through the tunnel.

There are various bridges in the course of this pipe-line, the most important of which consists of a bridge constructed to carry the pipe across the North Esk River. It is of masonry, with an arch of 45-feet span (Fig. 13).

The aqueduct was executed by Mr. James Young, contractor, Edinburgh, and cost £17,160. He also executed the contract for the laying of the main pipe to Edinburgh with its accompanying works. The total length of this pipe is 8½ miles, and it cost £21,270, not reckoning the cost of the pipes, which were delivered at £7 1*s.* 6*d.* per ton. The pipes, both for this and the inverted siphons upon the line of the aqueduct, were provided by Messrs. Laidlaw, of Glasgow. The pipes varied from ⅜ inch to 1 inch in thickness, according to the pressure which they would have to stand. The thickness of the pipes for the respective positions was derived by calculating the pressure at each portion of the line by the following formula:—

$$t = 0\cdot000075 \times d \times h + 0\cdot375 \text{ inch},$$

when d = diameter in inches, and h = the head in feet.

The main pipe delivers into the service-reservoir constructed within 3 miles of Edinburgh at Alnwick Hill, at which place the filters have also been erected (Plate 4; Figs. 14, 15, 16, 17, 18, 19, 20). The natural formation of the ground being of boulder clay rendered the watertightness of the reservoirs, &c., comparatively easy to secure; but, as is sometimes found underlying compact blue clay, beds or pockets of sand occasionally appear, thereby

rendering it necessary, in order to be certain that the works should be watertight, to carry down the puddle-trench to a depth considerably exceeding what otherwise would have been necessary.

The service-reservoir has an area of 5 acres; it is 900 feet long and 240 feet wide, constructed with an inside and outside slope of 2½ to 1. The excavation from the bottom of this reservoir went in a great measure to form the embankments, but a number of boulders which were found to exist in the natural clay were available for the purpose of making metal for the filter-beds. The inside slopes of the reservoir are protected by pitching in the usual manner, and the outside slopes are covered with grass. There are two outlets; one of them consists of a masonry tower, horseshoe in outline, inside of which is fixed a cast-iron upstand-pipe constructed with sluices, by means of which the water can be drawn from any required level, the object being to procure it as near to the surface as possible. Another masonry tower contains the emptying sluice, and serves at the same time as an overflow for the surplus water of the reservoir. There are four filter-beds, fed by an arrangement of piping which leads away the water from the regulating-tank, on the lower side of the embankment, into which the pipe from the cast-iron upstand discharges. The filters are each about ½ acre in extent, and they were designed for the purpose of passing 9,000,000 gallons per day, supposing three of them to be working and the remaining one in process of being cleaned. The retaining-walls of these filters are, from the foundation to the upper side of the coping, 12 feet in height, with an average thickness of 4 feet, and a batter upon the water face of 1 in 10. They, along with the cross-walls, which have the same batter on the face, are 3 feet 6 inches in width on the under-side of the cope, and were constructed with a void in the centre 4 inches in width, which was subsequently filled up with strong Portland cement concrete. On each side of this void are dovetailed recesses, 12 inches by 6 inches by 6 inches, constructed for the purpose of binding the walls together, and at the same time making them impervious to the passage of water. The result is satisfactory, inasmuch as not a drop of water passes from one filter to the other when one of them is empty. The floors of the filters are covered with a coating of 6 inches of Portland cement concrete, which is connected with the internal concrete of the side walls, and the filtering material is 6½ feet in depth. This consists of a bed of 3 feet 3 inches of broken stones, such as road metal, for the most part procured from the boulders found in the excavation of the ground

during their construction, and which consisted of rock of various formations, granite, whinstone, &c. Upon this there is a layer of 6 inches of gravel, of the size approaching to walnuts; over this again is another layer of the same thickness of gravel more approaching to beans; above this is another layer of 6 inches of coarse sand, and the whole is finished with a bed of 18 inches of fine sand. The gravel for this work was for the most part procured from a pit situated within ½ mile of the place, and the sand, which was riddled out of this gravel, was also used for the upper layers, while a certain quantity was brought from the River Tay at Newburgh, where sand, excellent for the purpose of filtration, can easily be procured free from imperfection, unlike the native sand above alluded to, which sometimes is very dirty.

The water is drawn off the filters by an arrangement of fire-clay pipes, commencing at the extremities at 6 inches in diameter, and increasing by degrees till they attain the diameter of the outlet-sluice, which is 22 inches in diameter. A regulating-well is attached to each filter, by which the rate of filtration can be increased or diminished by the sluice which regulates the difference of level by which the water is filtered. When perfectly clean, a difference of level of not more than 1 inch is sufficient to pass the regulation quantity of 1,030 gallons per square yard per day;[1] but after having been in operation for some days or weeks the difference of level between the water inside and outside requires to be increased.

The clear-water reservoir has a capacity of 4,500,000 gallons. It is 335 feet long and 120 feet wide. The retaining walls are similar to those already described for the filters, with the exception that there is no interior concrete core, and the batter on the face is 1 to 10.

From this clear-water reservoir the water is discharged into the measuring tank, the dimensions of which are 40 feet by 22 feet. The pipe communicating between these two structures is furnished with a swiftly-shutting sluice, by which the rate of discharge at any hour of the day can readily be ascertained. The house is furnished with a set of screens of copper-wire cloth, set in the form of a half circle, through which all the water going into Edinburgh must pass. Three pipes deliver from this reservoir, one being connected with the original old Crawley pipe, which has been made to discharge into the clear-water reservoir, and two

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[1] The regulation volume in the Metropolitan waterworks is 540 gallons per twenty-four hours from each square yard or filter.

pipes are laid in connection with the Moorfoot supply, one of which is led towards the centre of Edinburgh, and the other by way of Holyrood and the eastern districts towards Leith.

Some difficulty was found from the fact that the water used in washing the sand for the filters, both during their construction and during their use, was charged with earthy materials to such an extent as to silt up the course of the stream into which it naturally flowed; therefore it was necessary to construct subsiding ponds, into which the water from the sand-washer is allowed to flow and settle, and the result is, that after some days resting in these ponds the water can be discharged into the stream without damaging the water-course. It may be mentioned that there is a washing apparatus in the centre of each filter-bed, and it is found, judging from the experience of the last five years, sufficient to wash the sand of each filter once in four weeks. This has been carefully done, and the cost of this operation has, after a series of years, been found not to exceed 2*s.* 2*d.* per 1,000,000 gallons.

Compensation-Reservoirs.

In order to compensate for the abstraction of the water for the water-supply of Edinburgh from the Tweeddale burn and Portmore loch, it was necessary to construct the reservoir on the Fullarton burn. The site selected for this reservoir is particularly advantageous, the natural formation of the rocks rendering it necessary to construct an embankment of very small extent.

To complete the scheme, and, in order to afford compensation to the South Esk proper, another compensation reservoir was required at Rosebery. The details of the construction of these two reservoirs are so similar that one account will suffice for both.

Edgelaw reservoir (Fig. 21, Plate 3) has a capacity of 44,000,000 cubic feet; it covers an area of 37 acres, has a maximum depth of 80 feet, and the length of the embankment is 240 feet. The design of these works differs materially from that of the Gladhouse reservoir, previously described. In it, it was of importance to have appliances to draw off the water at levels as near the surface as possible, and for this reason the upstand tower was constructed within the area of the reservoir.

In the case, however, of the Edgelaw and Rosebery reservoirs, which are intended entirely for compensation purposes, and where the quality of the water is a matter of no importance, the outlets were placed at the bottom of the reservoirs.

At Gladhouse the inner portion of the outlet-culvert, between

the upstand and the puddle-wall, was necessarily under pressure from the water in the reservoir, as the upstand-shaft was constructed at the inner end of this culvert. In Edgelaw and Rosebery, however, the upstand shaft containing the sluices has been constructed immediately in front of the puddle wall, and the water obtains free access to the interior of the culvert for its whole length, as far as the upstand shaft (Figs. 22, 23, 24, 25). The section of this culvert was so designed as to carry off what, during the construction of the works, was calculated to be the greatest probable flood from the respective drainage-areas, and its dimensions are 10 feet by 9 feet 3 inches. It has a circular invert, with circular walls and roof. It is built of brickwork set in Portland cement, consisting of four rings at the outer and inner ends, where the pressure bearing upon it is least, and increasing by degrees until the thickness of seven rings is reached in the centre of the embankment; and over these rings of brickwork there is a layer of 2 feet of Portland cement concrete. The bricks used for this are ordinary composition bricks from a neighbouring factory, while the inner ring is composed of durable Staffordshire blue bricks. The side-walls rise from skew-backs of stone, which are necessary in order to bring together its parts which have different radii.

The upstand-shaft, which is only intended to be used for drawing water from the lowest levels of the reservoir, is also composed of brickwork; it consists of an outer and inner chamber, the interior dimensions of which are 9 feet by 8 feet and 5 feet respectively; while the walls of the structure, commencing at the bottom with an outside measurement of 36 feet by 29 feet, are reduced as the structure rises by means of buttresses and bevelled edges or intakes, until an outside measurement of 22 feet by 15 feet is reached at the level of the top of the embankment. Where the shaft rises above the level of the embankment it is constructed throughout of ashlar masonry; though the lower portion of the shaft waterways were left of a size equal to that of the outlet-culvert, to enable the flood waters to escape during the execution of the work; the down-stream one of which is 10 feet thick, while the midwall between the two chambers is 5 feet. This latter was filled with ashlar stones, carefully adjusted and radiated on their beds and joints before being placed in the work, and put together with Portland cement. The outer plug, or barrier, through which was built two outlet pipes 18 inches in diameter, is constructed of ashlar masonry on the inner face, and

the remainder of brickwork in cement. These plugs have proved sufficiently watertight, and only a slight indication of dampness can be seen on the outer surface of the down-stream one.

The waste-weir (Fig. 21) consists, in plan, of a Gothic arch with a length of crest of 180 feet. The crest consists of a single stone, 2 feet by 18 inches, bedded carefully upon a concrete foundation set upon the natural boulder clay, and backed up on each side with hewn pitching 15 inches in depth, set with a gradient of 1 in 4.

The weir-channel is contracted gradually to 30 feet in width where it is confined by masonry walls, during the remainder of its course. There are various arched courses in the paved portion of the channel, for the purpose of preventing any likelihood of serious damage in the event of any of the pitching being washed out. At Edgelaw there are two flights of altar steps, separated by a small portion of pitching, the upper flight containing nine steps and the lower one fifty-one steps; each step has a rise of 15 inches, with a head of 30 inches, and all are set upon a bed of concrete, carefully laid upon the surface of the natural rock excavation of this portion of the side of the valley.

After Edgelaw embankment had been completed, or nearly so, some difficulties were encountered on account of slips which took place on the inner face of it, the material of which it was composed consisting for the most part of clay; and it was probably due to the too copious addition of water to enable its being properly put together that these slips occurred. No doubt, when constructing embankments of materials such as this, care should be taken to see that a sufficient amount of solid material is incorporated with it, and also that too much water is not allowed to be poured over it, otherwise slips will be the inevitable consequence.

The puddle-trench in this reservoir was formed through satisfactory material, although a considerable geological fault was found to run right across it. The nature of the valley, which was very narrow at the bottom, was such as to cause some difficulty in the construction of the lower portion of the embankment, as the water had to be diverted from its original channel into a temporary one during the construction of the outlet-culvert, and the restricted area at command rendered this rather a matter of inconvenience and difficulty. Very little water was encountered during the sinking of the puddle-trench, until one spring was met with which threatened to cause trouble. This spring was concentrated and led away by a perforated iron pipe, and the whole neighbourhood of it was weighted by a substantial mass of con-

crete, and no trouble has been experienced in consequence of its existence.

The works at Rosebery (Plate 4, Figs. 26, 27, 28) resemble these in all respects, except that the waste-weir channel, owing to the configuration of the ground, has been divided into five series of steps, the total number of which is sixty. The embankment here is 470 feet in length, with a maximum depth of water of 75 feet; the area of the reservoir is 52⅓ acres, and its contents 60,000,000 cubic feet. The puddle-trench in this reservoir, which is still in progress, has proved a more difficult matter than that of Edgelaw. A satisfactory watertight foundation was reached in the bottom of the valley, which was taken down through 8 feet of gravel and other surface material, through 15 feet of hard limestone rock, till it reached a bed of impervious shale. The stratification is almost horizontal, and across the bottom of the embankment there is a fault whereby the strata are lowered towards the north about 3 feet.

Some anxiety was felt as to how this fault was to be dealt with, which crosses the puddle-trench diagonally, but after considerable trouble a satisfactory bottom was obtained, and there seems to be no fear of instability from its existence. The strata which overlie the compact limestone consist of very open-jointed limestone rock, some of the fissures in which are several inches in width, and in which several water-runs, of about 6 inches in diameter, are occasionally found. The west of this puddle-trench has been satisfactorily executed; the other side is in progress, and a watertight foundation has been reached at no very excessive depth. As a precaution against any escape of water past the end of it, a sheeting of puddle has been laid over the whole base of the embankment, 2 feet in thickness, connected with the clay in the puddle-wall, so that, if necessary at any future time, this puddle sheeting may be extended over the outside of that portion of the sides of the reservoir which consists of this open material.

In the Appendix will be found Tables giving the principal dimensions, approximate cost, and other particulars relating to the various reservoirs and works.

The Moorfoot works were designed and carried out by Messrs. J. and A. Leslie, Mr. Alexander Jervis, Assoc. M. Inst. C.E., acting as Resident Engineer, under whom were placed several inspectors, and they, and all the original works connected with the Pentland supply, are under the charge of the Author's firm, Messrs. J. and A. Leslie and Reid.

For a long time the quality of the Moorfoot water was a subject of anxious inquiry, since many of the opponents of the scheme averred that it was unwholesome, but the question has been put at rest. The following extract from a report by Professor Crum Brown and W. Buchanan will serve to show that it is of excellent quality.

"The weather was very inclement—cold east wind blowing during the day, with frequent falls of snow. The reservoirs and filter-beds were covered with ice. We collected samples of the four waters, viz.: A. Water of the Gladhouse reservoir as it enters the measuring-tank at Gladhouse. B. Mixed water of Portmore and Gladhouse from the measuring-tank at Gladhouse. C. Water as it leaves the filtering-tank at Alnwick Hill. D. Water from the measuring-tank at Alnwick Hill.

"The temperature of each water was taken at the time of collection, and was as follows:—

A, 34° F. B, 34°·1 F. C, 34° F. D, 37° F.

"We have carefully analysed these samples, and have determined, in the case of each of them—1st, the colour; 2nd, the amount and character of suspended matter; 3rd, the amount and character of the total solid residue left on evaporation, and the effect of ignition on the residue; 4th, the amount of oxidisable matter in the water, as measured by the oxygen required to oxidise it by Tidy's permanganate method; 5th, the hardness of the water; 6th, the ammonia and ammonia-yielding compounds, by Wanklyn's method; 7th, the chlorides contained in the water; and 8th, the nitrates and nitrites.

"The results of these analyses lead us unhesitatingly to the opinion that all these four samples of water are of excellent quality, and well adapted for the water-supply of a town. The only objection that could be taken to any of them is in reference to colour. Although under the remit we were not able to examine any primary source of supply except Gladhouse, it is evident from our results that this objection applies specially to the Gladhouse water. In reference to this, it is worthy of note that, although the Gladhouse water is more strongly coloured than any of the other waters examined by us under the remit, it cannot be called a very highly coloured water; and, further, that it is in every other respect at least as good as the other samples. The colour is certainly of vegetable origin, and cannot be regarded as injurious.

"Under the remit we were authorised to collect samples of the four waters at various times, so as to obtain fair average samples.

We have contented ourselves with samples collected on one occasion only; partly because the state of the weather and the condition of the roads made it very difficult to make more visits to Gladhouse, but also because our examination of the samples obtained on that one occasion has led us to the opinion that they are fair specimens of the various waters."

The Paper is illustrated by numerous diagrams and small-scale drawings, from which Plates 2, 3, and 4 have been engraved.

GENERAL APPENDIX.—

TABULAR STATEMENT of the DATES of CONSTRUCTION,

NOTE.—The distances by road from Edinburgh are measured from the

Name.	Character.	Date of Execution.	Distance from Edinburgh. By Road.	Distance from Edinburgh. By Pipe-line.	Surface Area.	Greatest Depth.	Capacity.	Coefficient for finding Contents $a \times d \times c$.	Greatest Height of Bank.	Cubic contents of Embankment including Puddle, Pitching, Soiling, &c.
			Miles.	Miles.	Acres	Ft.	Gallons.		Feet.	C. Yds.
Comiston	Springs	1681 and 1720	3·35	3·00	..	..	..	..	..	..
Swanston	"	1761	5·15	3·90	..	..	..	..	..	..
Crawley	"	1822	7·30	8·50	..	..	..	..	..	..
Glencorse	Reservoir	1822	8·30	9·50	52	62	359,373,000	0·409	77	86,335
Loganlea	"	1851	10·30	..	18⅛	55	121,875,000	0·440	59	102,000
Clubbiedean	"	1850	6·20	5·50	12⅜	44	65,625,000	0·429	55	69,052
Torduff .	"	1851	5·60	4·90	11⅜	80	112,500,000	0·439	85	177,600
Bonally .	"	1853	6·60	..	14⅛	25	53,125,000	0·538	32	37,074
Threipmuir	"	1847	8·50	..	112	23	206,250,000	0·289	29	34,553
Harlaw .	"	1848	8·00	..	30⅛	64	168,750,000	0·318	67	72,96
Castlehill	"	1851	0·30	..	..	30	1,715,625	..	30 (all masonry)	..
Black Springs	Springs	1848	..	8·50	..	..	..	..	..	..
Bavelaw and Listonshiells	"	1848	..	10·50	..	..	..	..	..	..
Colzium .	"	1859	..	15·00	..	..	..	..	..	..
Harperrig	Reservoir	1859	12·20	..	173⅛	38	562,500,000	0·314	36	54,58
Crosswood	Springs	1868	..	18·5	..	..	..	..	..	..
"	Reservoir	1868	16·00	..	62	40	175,000,000	0·259	48	88,06

[1] After including the registered

PENTLAND WORKS.

PRINCIPAL DIMENSIONS, COST, &c., of the VARIOUS WORKS.

Mound at Princes Street, and those by pipe-line from Castlehill Reservoir.

Proportion to Contents of Reservoir.	Drainage Area.	Length of Waste Weir.	Greatest Observed Depth Flowing over Weir.	Maximum Discharge per Acre of Drainage Area.[1]	Average Yield in Gallons per Day.	Engineers.	Name of Contractor.	Approximate Cost.	Cost per Million Cubic Feet of Storage.
	Acres.	Feet.	Inches.	C. Feet per min.				£.	£.
..	..	..	..	..	126,000	Desagulier	Krauss & Covay	..	..
..	..	..	..	..	300,000	..	..	..	..
..	..	..	..	..	600,000	Telford Jardine	..	..	..
1 : 24·7	3,964	60	..	8½	..	”	..	43,000	747
1 : 73·0	1,426	50	26	12	..	James Leslie	Wm. Scott	11,364	582
1 : 12·2	250	7	..	..	..	”	John Barr & Co.	6,021	573
1 : 3·7	758	30	..	..	..	”	K. Mathieson	13,467	748
1 : 8·4	110	10	..	..	..	”	Jas. McIntosh	3,500	411
1 : 35·3	3,613	90	14	12	..	Jardine	John Alexander	10,000	303
1 : 13·7	3,934	100	15	10	..	James Leslie	Alex. Morrison	7,778	288
..	..	..	..	..	..	”	John Alexander	10,153	..
..	..	..	..	..	400,000	J. Jardine Jas. Leslie	..	..	..
..	..	..	..	..	2,000,000	”	Alex. Wilson	..	..
..	..	..	..	..	1,950,000	James Leslie	..	..	..
1 : 61·1	4,217	100	13¼	5·8	..	”	John Alexander	11,548	128
..	..	..	..	..	700,000	”	John Pollock	..	..
1 : 11·7	2,113	50	10	3·8	..	”	Robt. Moffat	20,686	738

discharge from sluices.

MOORFOOT

TABULAR STATEMENT of the DATES of CONSTRUCTION,

NOTE.—The distances by Road from Edinburgh are measured from the

Name.	Character.	Date of Execution.	Distance from Edinburgh.		Surface Area.	Greatest Depth.	Capacity.	Coefficient for finding Contents $a \times d \times c$.
			By Road.	By Pipe-line.				
			Miles.	Miles.	Acres.	Feet.	Gallons.	
Portmore[1] .	Reservoir	1879	17·37	16·95	102½	12½	250,000,000	..
Portmore .	Aqueduct	1879	17·37	..	..	..	..	..
Tweeddale burn . .	do.	1879	16·86	14·24	..	..	..	..
Gladhouse[2] .	Reservoir	1879	15·86	13·42	399	68½	1,713,356,000	0·230
Gladhouse[3] .	Aqueduct	1876	15·86	..	..	..	..	..
Gillygubdean	Cistern .	1876	14·31	11·60	..	..	..	..
Pipe to Edinburgh[3]. .	Conduit.	1877	14·31	..	..	..	..	..
Bridge over Esk . .	Bridge .	1876	8·10	7·45	..	..	..	..
Alnwickhill[1]	Reservoir	1879	3·60	3·30	5	24	19,904,263	..
do.	Filters .	1879	3·60	..	2·48	..	..	..
do.	Service Reservoir	1879	3·60	..	..	17	4,180,307	..
Edgelaw[4] .	Reservoir	1880	13·16	..	37	80	275,000,000	0·341
Rosebery[4] .	do.	..	13·68	..	52⅓	75	381,250,000	0·359
Main pipes[3] to Edinburgh . .	..	1878	..	..	..	..	..	..
Main pipes to Leith .	..	1878	..	..	..	..	..	..
Main pipes to Musselburgh . .	..	1880	..	..	..	..	..	..

[1] Ironwork supplied by Messrs. Oliver and Arrol, Edinburgh.

[2] Ironwork supplied by Messrs. Hanna, Donald, and Wilson, Paisley.

WORKS.

PRINCIPAL DIMENSIONS, COST, &c., of the VARIOUS WORKS.

Mound at Princes Street, and those by Pipe-line from Castlehill Reservoir.

Greatest Height of Bank.	Cubic Contents of Embankment, including Puddle, Pitching, Soiling, &c.	Proportion of Contents of Reservoir.	Drainage Area.	Length of Waste Weir.	Length.	Diameter.	Name of Contractor.	Approximate Cost.	Cost per Million Cubic Feet of Storage.
Feet.	Cubic Yds.		Acres.	Feet.	Miles.			£.	£.
16	16,068	1 : 92	610	20	..	..	W. Mackenzie	12,500	312
..	..	..	..	..	3·50	24 in.	do.	6,500	..
..	..	..	1,337	..	1·20	Segmental 7 ft. 4 in. radius.	do.	12,000	..
79	152,349	1 : 67	6,131	150	..	..	do.	63,400	231
..	..	..	..	..	1·72	4 ft. 6 in. × 3 ft.	James Young	17,600	..
..	..	..	..	..	..	12 ft.	do.	360	..
..	..	..	..	..	8·30	24 & 22 in.	do.	56,100	..
..	..	..	..	..	..	..	do.	1,000	..
33	107,521	..	..	..	..	..	Henderson and Matthew	18,800	..
..	..	..	..	..	..	..	do.	26,000	..
..	..	..	..	..	..	..	do.	21,200	..
93	93,050	1 : 17·5	6,363	170	..	..	James Young	35,000	795
84	175,403	1 : 12·9	7,751	170	..	..	Lawson & Best	33,000	541
..	..	..	..	..	..	22 in.	Henry Lake	23,800	..
..	..	..	..	..	..	22 in.	Steuart & Creber	30,200	..
..	..	..	..	..	..	10 in.	do.	4,000	..

[3] Pipes supplied by Messrs. R. Laidlaw and Sons, Glasgow.
[4] Ironwork supplied by the Glenfield Company, Kilmarnock.

Average Monthly Gaugings of Black Springs.

In cubic feet per minute.

	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882
January .	49·5	98·1	34·2	69·0	82·6	83·6	60·6	52·3	68·0	45·9	88·8	101·5	66·7	110·7	54·5	75·2	53·7	54·2	44·5	61·8	61·2
February	60·6	80·5	61·1	36·6	80·5	78·6	85·4	77·8	37·5	66·7	68·9	48·9	35·4	55·6	53·2	99·8	55·8	42·7	38·2	51·5	40·5
March .	54·2	31·7	82·2	52·4	72·0	38·8	58·5	50·6	65·7	47·9	45·7	46·1	22·5	45·7	76·5	41·7	39·7	64·0	56·6	62·2	78·5
April . .	48·1	29·4	84·6	27·6	69·9	47·3	50·1	29·3	29·9	51·1	71·9	32·8	42·2	27·6	54·9	54·9	26·2	65·2	46·5	30·2	48·8
May . .	41·1	28·2	25·4	35·6	39·7	44·2	44·2	30·0	23·1	47·3	71·0	23·7	21·1	21·3	45·7	49·7	26·6	38·7	39·5	26·6	62·6
June . .	36·8	34·5	18·6	31·3	26·4	41·7	24·3	25·3	16·5	23·6	46·6	21·7	13·2	16·3	25·7	33·4	33·2	42·5	24·2	24·3	28·0
July . .	29·7	27·4	14·8	21·1	19·4	53·2	17·9	20·6	14·4	19·1	31·3	17·1	10·2	14·8	21·1	50·9	23·5	132·2	17·5	19·8	25·8
August .	52·6	19·3	12·3	16·0	26·8	33·2	14·8	16·3	12·5	19·7	32·9	16·5	32·5	13·6	16·7	94·3	17·1	55·6	15·2	41·2	22·0
September	29·8	25·7	10·9	14·2	24·9	30·3	16·5	14·1	11·1	21·3	82·5	32·1	24·3	16·2	26·3	79·6	37·3	38·6	19·8	62·2	21·5
October .	46·9	36·4	47·8	75·7	27·8	24·5	28·6	23·1	11·2	32·9	58·0	77·5	56·0	43·2	58·2	35·6	49·6	30·3	34·8	48·2	34·2
November	51·3	52·6	71·4	55·1	51·8	26 0	57·8	24·7	15·1	53·1	115·4	86·9	42·5	68·6	59·1	69·3	52·4	35·8	55·4	45·2	52·5
December	51·2	59·0	64·6	55·9	64·1	22·8	65·2	38·1	26·5	65·2	79·9	38·1	77·7	76·1	80·9	57·7	65·5	38·2	61·5	60·0	73·0

AVERAGE MONTHLY GAUGINGS of BAVELAW and LISTONSHIELLS SPRINGS.

In cubic feet per minute.

	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882
January .	148·5	145·1	145·2	148·4	159·7	160·6	161·1	184·7	197·5	..	..	202·1	..	..	..	216·5	194·2	182·6	184·8	181·5	183·2
February	153·1	149·6	150·7	143·2	167·2	163·7	192·4	199·8	201·1	..	..	218·0	..	..	208·9	227·3	213·9	180·4	186·8	182·7	183·2
March .	145·6	145·9	148·5	143·2	160·7	154·6	190·4	166·2	200·6	..	..	222·4	..	..	231·6	184·6	207·9	183·1	188·2	185·6	199·9
April . .	150·1	144·4	146·3	137·2	163·9	161·3	185·5	175·2	189·8	..	..	212·7	..	..	204·3	223·8	198·1	187·8	187·0	177·8	188·8
May . .	147·1	145·9	141·6	136·8	165·3	154·5	179·9	197·8	185·8	..	..	307·5	..	..	194·3	205·5	204·3	185·8	187·0	174·0	188·8
June . .	146·3	148·6	138·4	145·5	151·1	169·2	177·4	197·0	180·5	..	..	193·4	..	..	..	205·8	194·4	185·0	178·8	170·2	182·2
July . .	141·2	141·0	135·4	151·0	144·6	165·7	168·0	191·4	..	..	..	..	..	..	..	210·2	188·7	193·9	174·5	170·8	181·0
August .	148·0	139·3	132·6	151·7	149·7	153·0	181·8	182·6	..	..	..	..	..	..	..	206·2	180·2	174·7	170·3	169·1	178·0
September	139·9	148·6	131·6	149·8	142·1	152·2	176·2	183·0	..	..	..	..	..	..	..	200·5	182·5	180·2	178·4	175·8	179·5
October .	145·2	146·0	133·3	163·6	148·6	150·9	179·7	179·8	..	..	247·9	..	..	..	..	192·9	203·2	186·5	172·5	175·2	184·2
November	142·4	144·6	139·5	152·8	154·3	150·5	186·9	186·5	..	..	252·1	..	..	..	174·6	220·7	180·6	185·5	177·0	176·4	187·5
December	144·8	149·6	142·7	159·5	158·0	174·5	201·7	191·7	..	..	250·4	..	..	..	181·3	215·4	186·4	205·8	181·2	155·0	192·0

AVERAGE MONTHLY GAUGINGS of COLZIUM SPRINGS.

In cubic feet per minute.

	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882
January .	246·9	255·3	237·6	245·5	245·2	246·3	215·0	224·0	224·0	..	..	224·0	..	..	220·0	224·0	224·0	221·0	221·0	221·0	224·0
February	254·2	261·0	244·9	227·6	246·5	255·3	224·0	224·0	224·0	..	..	224·0	..	..	221·6	224·0	224·0	217·0	223·0	222·0	223·0
March .	246·1	248·7	244·9	231·7	242·5	250·1	223·0	224·0	224·0	..	..	224·0	..	..	220·0	224·0	224·0	221·0	224·0	223·2	224·0
April. .	246·9	244·0	239·1	217·2	246·2	251·3	222·4	224·0	220·5	..	..	224·0	..	..	218·0	224·0	224·0	224·0	224·0	221·0	224·0
May . .	246·3	245·2	226·4	215·5	230·9	244·9	222·0	221·0	214·0	..	..	224·0	..	..	222·4	224·0	224·0	220·0	224·0	219·2	224·0
June . .	242·4	245·1	219·7	202·7	217·2	248·9	211·7	216·8	208·8	..	..	222·0	..	..	220·0	223·0	220·0	221·0	221·6	212·0	223·0
July . .	237·2	227·3	210·6	209·7	210·5	242·8	194·8	190·2	..	..	..	..	..	..	206·0	224·0	212·1	224·0	215·5	215·0	223·0
August .	250·2	221·2	203·3	207·1	216·6	235·3	191·5	202·2	..	..	..	..	..	..	200·2	224·0	205·0	224·0	199·1	209·1	220·8
September	236·4	235·0	207·1	200·9	213·3	231·0	196·8	205·0	..	..	..	..	..	..	219·5	224·0	218·0	224·0	205·8	212·5	220·0
October .	243·6	242·4	207·5	235·9	215·1	227·3	204·7	215·0	..	..	224·0	..	..	..	222·4	224·0	203·1	224·0	206·0	214·0	219·6
November	244·9	242·4	245·6	219·4	234·7	225·4	221·0	218·5	..	..	224·0	..	..	..	221·5	224·0	220·0	224·0	216·0	216·4	223·0
December	252·2	250·1	240·3	211·5	250·2	228·6	222·0	221·1	..	..	224·0	..	..	..	224·0	224·0	220·8	221·6	220·0	220·0	224·0

AVERAGE MONTHLY GAUGINGS of CROSSWOOD SPRINGS.

In cubic feet per minute.

	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882
January .	..	..	..	..	..	..	88·0	135·0	160·2	..	..	107·0	..	..	..	122·8	154·0	120·2	82·5	86·0	90·0
February	..	..	..	..	..	..	99·7	154·7	141·7	..	..	84·0	..	..	113·6	106·3	128·2	107·2	88·2	87·0	86·0
March .	..	..	..	..	..	..	93·2	117·7	152·7	..	..	92·5	..	..	110·7	93·3	137·2	119·2	87·4	90·6	81·5
April. .	..	..	..	..	..	..	88·8	135·5	126·5	..	..	94·0	..	..	93·2	108·3	128·6	133·4	84·0	80·5	91·5
May . .	..	..	..	..	..	..	88·5	126·0	113·7	..	..	74·2	..	..	101·7	121·6	121·8	109·5	80·0	75·4	106·8
June . .	..	..	..	..	..	..	74·2	109·1	116·4	..	..	108·0	..	..	90·5	90·3	128·0	85·0	75·0	66·2	91·2
July . .	..	..	..	..	..	..	67·1	89·2	..	..	..	..	..	..	92·8	92·1	110·1	105·1	74·0	69·8	80·2
August .	..	..	..	..	..	..	65·5	99·2	..	..	..	..	..	..	81·6	103·8	110·2	95·0	83·4	69·8	81·2
September	..	..	..	..	..	..	100·4	101·2	..	..	..	..	..	..	86·5	84·0	115·0	92·0	83·5	74·7	77·0
October .	..	..	..	..	..	..	118·5	104·0	..	..	..	..	..	..	78·6	100·1	97·4	83·5	75·2	73·2	85·6
November	..	..	..	..	..	..	133·5	137·0	..	..	107·5	..	..	..	81·0	118·0	98·0	88·5	89·4	77·4	82·2
December	..	..	..	..	..	..	122·0	143·7	..	..	90·7	..	..	..	83·3	108·0	118·4	88·8	84·7	85·0	97·5

MONTHLY REGISTER of RAIN and EVAPORATION at GLENCORSE, 700 feet Ordnance.

NOTE.—The Evaporation given in black figures.

	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
January	3·30	7·00	2·30	4·75	4·40	6·05	5·85	3·50	2·40	2·75	5·50	4·95	3·45	5·70	2·60	9·40	4·45	1·70	1·80	2·75	3·60
February	2·00	2·65	3·10	1·75	4·60	2·95	6·00	4·80	4·05	2·95	2·55	1·40	1·20	2·05	4·00	3·30	1·40	3·70	3·10	3·55	2·50
	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	**0·10**	..	..
March	4·70	0·95	4·05	1·40	1·85	1·85	3·85	1·55	2·10	1·80	4·60	1·50	2·25	1·55	6·10	2·45	1·30	4·00	2·70	4·50	5·25
	..	**0·50**	..	..	..	..	**0·20**	**0·30**	..	**0·35**	**0·35**	..	**0·35**	**0·35**	..	..	**0·80**	**1·10**	**0·70**	..	**0·60**
April	2·55	3·40	0·90	0·40	2·20	3·85	4·55	2·00	0·70	4·55	3·35	0·40	2·75	1·15	2·95	4·00	1·85	3·30	5·00	0·80	3·75
	1·05	**1·25**	**1·10**	**1·20**	**0·55**	**0·15**	**1·00**	**1·90**	**1·80**	**0·20**	**1·10**	**1·35**	**1·55**	**1·35**	**0·30**	**1·10**	**0·95**	**1·20**	**1·40**	**1·35**	**1·00**
May	3·40	2·10	1·90	6·00	2·00	2·80	2·50	2·85	1·60	0·70	5·20	2·50	2·00	1·60	1·60	3·20	3·90	2·30	2·50	3·40	2·40
	1·90	**2·05**	**2·45**	**1·10**	**2·40**	**1·15**	**2·55**	**2·00**	**1·65**	**2·40**	**1·65**	**0·90**	**1·70**	**2·25**	**2·45**	**2·00**	**2·10**	**1·70**	**2·20**	**2·40**	**2·30**
June	3·20	3·85	1·40	0·40	1·25	2·50	1·15	3·10	3·20	2·35	3·30	0·65	1·50	2·75	3·40	3·40	2·35	6·20	2·50	2·85	4·83
	1·90	**1·95**	**1·90**	**2·60**	**1·25**	**2·50**	**2·90**	**2·35**	**2·05**	**2·15**	**2·10**	**1·70**	**2·80**	**2·05**	**2·80**	**2·50**	**2·25**	**1·55**	**2·00**	**2·00**	**1·40**
July	3·80	0·65	2·35	3·40	4·75	7·65	0·55	0·95	1·95	3·15	3·75	3·85	2·40	3·85	2·35	6·20	0·50	11·00	3·95	4·10	3·75
	2·10	**2·85**	**2·35**	**1·30**	**2·55**	**2·00**	**3·00**	**3·00**	**2·45**	**1·60**	**2·15**	**2·10**	**1·20**	**2·45**	**2·95**	**2·20**	**2·95**	**1·80**	**2·00**	**2·65**	**2·00**
August	6·00	4·15	0·40	4·50	3·70	2·10	5·80	1·25	1·75	2·65	3·70	4·45	6·60	2·50	4·35	9·60	6·90	4·00	1·10	7·10	2·20
	1·90	**2·15**	**2·70**	**1·40**	**0·60**	**1·90**	**2·50**	**2·40**	**2·40**	**2·00**	**1·00**	**2·00**	**2·00**	**1·80**	**2·30**	**1·35**	**2·15**	**1·70**	**1·90**	**1·70**	**2·00**
September	2·05	4·75	3·55	0·70	3·65	2·40	4·55	5·65	2·50	3·10	6·15	3·40	3·20	4·50	4·50	2·05	4·40	2·15	4·10	4·25	2·95
	1·10	**0·95**	**0·65**	**1·80**	**1·25**	**1·40**	**1·45**	**0·85**	**1·40**	**1·15**	**0·60**	**1·60**	**1·25**	**1·05**	**1·20**	**1·40**	**1·80**	**1·35**	**1·60**	**0·65**	**1·50**
October	6·25	3·10	9·90	6·65	1·45	2·40	2·90	2·25	3·50	2·55	5·45	6·10	5·15	3·50	3·55	3·75	3·75	1·85	4·55	2·70	3·25
	0·30	**0·75**	**0·60**	..	**0·50**	**0·65**	**1·00**	**1·05**	**0·15**	**0·45**	**0·30**	**0·45**	**0·75**	**0·65**	**0·30**	**0·50**	**0·80**	**0·85**	**0·20**	**0·50**	**0·30**
November	2·05	2·65	3·25	2·95	2·50	0·25	3·05	2·70	1·55	4·70	5·75	4·20	4·70	5·75	4·20	3·95	3·80	3·85	6·25	3·85	4·40
	..	..	**0·40**	**0·10**	..	**0·70**	**0·10**	**0·30**	..	..	..	**0·10**	..	..	..	..	**0·15**	**0·40**	..	..	**0·15**
December	3·50	3·65	2·65	2·70	5·15	2·60	5·25	3·55	2·40	3·20	2·90	2·90	2·55	3·00	5·75	3·00	3·80	2·70	7·45	2·50	8·45
Total	42·80	38·90	35·75	35·60	37·50	37·40	46·00	34·15	27·70	34·45	52·20	36·30	37·75	37·90	45·35	54·30	38·40	46·75	45·00	42·35	47·33
	10·25	**12·45**	**12·15**	**9·50**	**9·10**	**10·45**	**14·70**	**14·15**	**11·90**	**10·30**	**9·25**	**10·20**	**11·60**	**11·95**	**12·30**	**11·05**	**13·95**	**11·65**	**12·10**	**11·25**	**11·25**

MONTHLY REGISTER of RAIN at MOORFOOT. 900 feet Ordnance.

	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882
January	..	6·22	3·92	3·17	..	..	..	3·26	6·78	1·43	8·87	4·60	1·45	1·45	1·41	2·60
February . . .	..	4·55	4·54	4·60	..	..	..	2·50	0·93	5·13	3·36	1·55	3·68	3·77	2·47	2·10
March	..	5·18	1·38	1·30	..	..	..	2·82	1·43	..	3·33	1·30	3·42	1·53	2·11	4·10
April	..	5·00	2·13	1·30	..	..	..	2·38	1·37	4·70	4·98	1·90	2·40	5·42	0·40	3·24
May	..	2·71	2·75	2·52	..	..	..	1·56	2·00	1·55	4·00	3·10	2·30	1·78	3·02	1·71
June	..	1·33	2·72	3·00	..	..	..	1·29	3·33	..	3·08	3·00	5·37	2·12	1·60	3·39
July	..	1·00	1·27	1·44	..	..	..	3·00	3·52	..	5·79	1·38	6·80	3·21	3·70	4·80
August	..	5·59	0·81	1·83	..	..	..	6·10	2·32	5·85	7·70	6·55	4·35	0·81	5·80	2·18
September . . .	2·63	4·61	5·35	2·50	..	..	..	2·75	3·64	5·15	2·60	3·93	2·32	6·01	3·95	2·53
October	2·35	4·19	2·38	4·44	..	..	..	4·45	6·04	2·62	4·64	3·13	1·60	4·14	3·25	2·80
November . . .	1·01	3·23	4·31	2·20	..	..	..	6·82	5·80	5·14	5·35	4·05	3·13	5·07	2·56	4·20
December . . .	2·33	5·61	2·94	3·28	..	..	..	3·67	3·46	8·45	2·85	4·05	1·68	3·77	3·07	3·30
Total . . .	8·32	49·25	34·50	31·58	..	..	..	40·60	40·62	..	56·55	38·54	38·50	39·08	33·34	36·95

(*Paper No. 1914.*)

"The Waterworks of Port Elizabeth, South Africa."[1]

By John George Gamble, M.A., M. Inst. C.E.

I. Introduction.

Port Elizabeth is the principal commercial port of South Africa, and lies midway between the Cape of Good Hope and Natal. The term "Algoa Bay," sometimes used synonymously for "Port Elizabeth," strictly applies only to the portion of sea-coast which is more or less sheltered by Cape Recife.

Till quite recently the water-supply of Port Elizabeth was very scanty; the lower, or business part of the town drew water from a main laid along the beach from a small valley called Shark's river, in the sand-dunes between Port Elizabeth and Cape Recife; but the upper town, where most of the best houses have been built, was dependent on underground tanks, in which the rain from the roofs was stored.

As the rainfall is much better distributed throughout the year at Port Elizabeth than at most places in South Africa,[2] houses that had large roofs and large tanks were able to get along fairly well; but the poorer houses were badly off, and during droughts, according to the evidence of a former mayor, very indifferent water was sold for 2*s.* 6*d.* a barrel, the barrel being occasionally filled from the horse-trough instead of from the appointed pump. One witness before a parliamentary committee said he sometimes paid £1 a day for water brought to his house. The quantity of the Shark's river water was small, for, though the proprietors claimed to be able to deliver 120,000 gallons per diem, yet they did not supply more than 50,000 to the town. The pressure was low; the intake was only 60 feet above sea-level, and the quality was bad, the water containing magnesia salts.

Such being the condition of things, endeavours were early made to provide a better supply. In 1861 the then town engineer was instructed to make surveys for this purpose; prizes were offered

[1] The discussion upon this Paper was taken together with that upon the preceding and following ones.

[2] The annual rainfall at Port Elizabeth, taking the mean of thirteen years, is 24·36 inches. January is the only month in which the mean fall is small (0·85 inch); the mean fall in every other month is above 1·60 inch.

and awarded for the best schemes, and subsequently two separate attempts to obtain parliamentary powers were made without success. In 1876 the Author, at the request of the Town Council, examined all available sources, and came to the conclusion that only two schemes would be thoroughly satisfactory. One scheme was to obtain a share of a spring of water belonging to Uitenhage, a town upwards of 20 miles distant. The people at Uitenhage allowed half of the water to waste in a leaky channel between the spring and the town; but they objected strenuously to the alienation of any of it even on the most favourable terms. Hence Port Elizabeth was thrown back on the second scheme, which has now been carried out, and is the one described in this Paper.

II. General Description.

Some 25 miles to the west of Port Elizabeth is a tract of hilly country, forming a spur of the great Winterhoek range. At the southern edge of this tract lies the Witteklip ridge, a conspicuous landmark from Port Elizabeth. The basin of the Van Staaden's river is inland from Witteklip, and through the Witteklip ridge the Van Staaden's stream flows in a narrow gorge to the sea.

The rainfall in this basin appears to be both greater and steadier than at Port Elizabeth, and much more so than at Uitenhage, the high ground apparently forming a condenser for the sea-mist which are driven upwards over it by the onshore south-east wind. Gaugings of the stream were taken and found satisfactory, the discharge of the feeder chosen for the Port Elizabeth supply never falling below 350,000 gallons per day, and very seldom below 500,000 gallons.

Preliminary surveys were carried out under the Author's instructions. By this means it was shown that a tunnel, which had been suggested, would not be advisable, and that it would be better to carry the pipes down the Van Staaden's stream and along the rocky winding gorge through the Witteklip for 3 miles before reaching the gently undulating flats, which stretch the whole way on to Port Elizabeth. It was also shown that, in order to carry the water over these flats, the intake must be above a point called the Waterfall. The total distance from the intake to the landing jetty at Port Elizabeth is 28 miles.

Having established the line along which pipes would have to be laid, parliamentary powers were obtained for borrowing money and for interfering with private property.

Before framing the specifications for the works, the Author obtained permission from the Town Council to send to England for a resident engineer. Mr. J. Hamilton Wicksteed, Assoc. M. Inst. C.E., was selected for this post, and he arrived in the colony in January 1878. He immediately set to work on the necessary surveys for a complete determination of the pipe-track, and subsequently drafted and, in consultation with the Author, drew up the specifications for the seven contracts under which the work was carried out. Mr. Wicksteed saw the water being distributed in Port Elizabeth, but before the completion of the service-reservoir his death occurred, in September 1881.[1]

Plate 5, Fig. 1, is a map of the neighbourhood showing the Van Staaden's river, the direction of the pipe-track, and the town of Port Elizabeth. Fig. 2 gives the longitudinal section of the main from the intake to the town, and shows the position of the various sluice-valves, waste-valves, air-valves, access-bonnets, &c. The general features of the work consist of a small intake weir in the mountains from which a cast-iron main is laid throughout to Port Elizabeth, communicating with, and also passing by, a service reservoir at the highest point of the suburbs of the town. As will be seen from the section, several mean gradients were adopted, and several sizes of pipes were used. The pressure is relieved or "broken" at three points between the intake and the town. The third break-pressure tank was used temporarily during the construction of the service reservoir. At present the service reservoir acts as the third relieving tank. The gradient has been so arranged that if desirable a storage-reservoir and filter-beds can be introduced at Parkin's Vley,[2] 23 miles from the intake.

The supply originally proposed by the Author was 500,000 gallons per diem, the population of Port Elizabeth in 1876 being under 14,000; but the Town Council determined to have a larger quantity. The present main was designed to carry 840,000 gallons per diem, allowing for a possible incrustation in the pipes reducing their diameter by 1 inch. Clean pipes of the sizes and with the gradients given below, deliver, according to received formulas, close upon 1,000,000 gallons in the twenty-four hours. From actual measurement the main itself gave on one occasion at the rate of 930,000 gallons, on another 960,000 gallons in the twenty-four hours.

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[1] Minutes of Proceedings Inst. C.E., vol. lxvii., p. 413.

[2] A "vley" is a shallow lake not necessarily always containing water.

Distance.	Size.	Gradient.
	Inches.	
From intake to 14½ miles (break-pressure tank, No. 1) .	12	1 in 394·3
„ 14½ miles to 19¼ miles	10¾	1 in 201·4
„ 19¼ „ „ 21 „ (break-pressure tank, No. 2)	9½	1 in 106·7
„ 21 „ „ 22¾ „ (Parkin's Vley)	9½	1 in 90·8
„ 22¾ „ „ 26¼ „ (the service-reservoir) . .	12	1 in 326·7
Service reservoir to town	16	..

The size of the main from the service-reservoir to the town is very large, although the gradient is steep, in order to give a greatly increased discharge of the main in case of fire.

III. The Contracts.

It will be convenient to describe the work according to the various contracts under which it was carried out.

The first contracts for which tenders were invited were:—Contract (i.) for the manufacture of the pipes and special castings for the main from the intake to the town, and the delivery of them on the beach at Port Elizabeth. Contract (ii.) for the transport of these pipes and fittings from the beach to their proper places; for laying and jointing the main, as well as for constructing the intake-works, break-pressure tanks, valve-holes, and fixing the valves. These two contracts were advertised together in England and the colony. Contract (iii.), advertised in England, was for the valves and fittings. Contract (iv.), advertised in England, was for the manufacture of pipes for town-distribution. It was not practicable to include this with contract (i.) as there was at first no trustworthy map of the town, and a special survey had to be made by Mr. Wicksteed for the purpose. To save time, tenders were selected in England by Mr. Robert Stewart, of the Standard Bank of British South Africa, under the advice of Mr. J. Wolfe Barry, M. Inst. C.E., who had been appointed by the Town Council to act on their behalf. Contract (v.) was for laying and jointing distribution pipes, fixing the hydrants and public fountains. This contract was advertised and let in the colony. Contract (vi.), which in the rapidly-growing town of Port Eliza-

beth has become an annual one, is for fixing the house-services. Contract (vii.) was for the service reservoir, also advertised and let in South Africa.

Contract (i.)

Contract (i.) was let to Messrs. Hopkins, Gilkes and Co., now the Teeside Iron and Engine Works Company. This firm undertook to deliver the pipes on the beach at Port Elizabeth, the Council only paying Customs duties and wharfage dues. As there are no docks at Port Elizabeth, and as goods have to be landed in surf-boats belonging to certain landing companies, the Council undertook to reimburse the contractors for all necessary charges over 8*s*. 6*d*. per ton. A sum of £300 extra was incurred under this head. Messrs. Hopkins, Gilkes and Co.'s tender was £37,889, and the amount paid £37,701. Of the total sum paid under the contract £35,148 was for straight pipes, for which the price was £7 per ton, and £2,060 for special pipes, including bends, access-castings, branches, &c., at £13 per ton. The pipes were badly stowed on board the sailing vessels on which they came out, having no packing of any sort between them, and 32 per cent. were found cracked when landed. Most of these pipes, being only cracked for a short distance from the spigot-end, were cut by the Council, and the expense of cutting, as well as the value of the iron removed, was deducted from the certificates. The pipes being of hard Cleveland metal, it was not found convenient to cut them with a lathe or machine, and they were all cut by hammer and chisel. A pipe-cutting machine was tried, but as four sets of cutters were used up on eleven pipes it was abandoned. All the pipes were tested on the beach, but the cut pipes gave rather more trouble than the others, on account of their rough ends. However, by use of extra pads and greater pressure in screwing up, this difficulty was overcome. In subsequent contracts the Author has specified pipes to have a wrought-iron ring, about 1 inch broad and ½ inch thick, shrunk on the spigot end. This has been found to give great protection, and the number of breakages of pipes so protected has been comparatively small. The rings are knocked off before the pipes are laid. For the purpose of testing on the beach, a press was fitted up, worked by an Otto gas-engine. The cracked pipes were almost always discovered before the testing, and very few gave way in the press; but the testing was of great service, enabling the Council to be sure of the soundness of the pipes when handed over to the contractors for contract (ii.). Plain socket-and-spigot pipes were adopted, but the sockets are only 2¾ inches deep, being

much shorter than usual (Fig. 3). This was owing to the advice of Mr. Wicksteed, who wrote to the Author, "Deep sockets look as if they give stiffness to the joints, whereas in reality it is only the depth of the lead joint that gives the stiffness, and for this 1½ inch has been practically found quite sufficient. It is impossible to ram the yarn at the back of the lead so hard as to stiffen the joint to any useful extent; at any rate, you can never get it done, and if the joint was by any means made absolutely stiff and rigid, it would be a very questionable advantage." The diameter of the socket is made smaller behind the lead joint to save unnecessary yarn; to ensure the pipes being put together tolerably concentrically; and to make it difficult to "swag" the pipes much. Bends were used where deviations from the straight line were unavoidable. But the chief reason for this contraction of diameter behind the lead was to force the pipe-layer to ram the yarn back beyond a certain definite point. Any pipe-layer discovered allowing the yarn to be at any point in front of the shoulder should be dismissed. Moreover, when the inspector stands over the workmen, he can distinctly hear, by the sound of the tool, whether the yarn is being driven back behind the shoulder or not. The pipes have a hole ½ inch in diameter drilled in the socket, so as to let air out at the time the joint is being run with lead. This hole is subsequently calked with a punch. When the pipes are dry at the time of running, the hole almost always becomes full of lead. These holes should be drilled, and not cast with the pipe; it was found that when casting was tried, the metal was occasionally honeycombed, or weakened round the air-hole, and in consequence such sockets were split while being calked. The ordinary pipes of larger diameters were obtained in 12-feet lengths, except for a portion of the gorge where, for convenience of carriage, 9-feet lengths were adopted.

The bends (one hundred and ninety-five in number in the specification) were of 15-feet radius, with the exception of eight bends of 45°, placed in special positions, of 5-feet radius, through which it is not intended that the ordinary scrapers shall pass. The bends give various angles of deviation from 2½° to 15°, the amount of deviation being obtained by varying the lengths without altering the radius, thus avoiding confusion.

All the pipes and other castings were coated with Angus Smith's composition. This coating should, in the Author's opinion, be put on immediately after the pipes are cast, without even waiting for testing. This is of special importance if any fettling is done, as the parts so fettled become rusty much quicker than where the

skin is undisturbed. The Author has found in pipes otherwise well coated that rust had established itself at a fettled place, and was apparently working its way under the varnish.

The lengths and weights of the pipes specified were as follow. The pipes actually sent out did not differ materially in weight from that given by these figures.

Internal Diameter.	Length.	Number.	Approximate Average Weight per Pipe.	Proof Pressure.
Inches.	Feet.		lbs.	Feet of Water.
16	12	620	1,400	300
14	12	220	1,260	500
12	12	2,700	910	300
12	12	3,920	952	400
12	9	1,370	755	600
$10\frac{3}{4}$	12	2,170	784	300
$9\frac{1}{2}$	9	2,100	497	400
$9\frac{7}{8}$	9	140	553	600
6	9	60	266	600
3	9	1,000	112	600

The pipes, 3 inches in diameter, were used for distribution in the streets along which the main passed, and were ordered in this contract so as to be laid in the same trench with the main.

Contract (ii.)

Contract (ii.) was let to Messrs. John Mackay and F. W. North for the sum of £26,999. The pipes, as well as the bends, special castings, and requisite valves, were handed over to the contractors at the testing-yard, and the contractors conveyed everything to its proper position, excavated the pipe-trench, laid and jointed the pipes, besides building the intake weir, three break-pressure tanks, and a large number of valve-pits.

The intake weir is of Portland cement concrete, for the making of which there were good facilities, excellent clean sharp sand being found in the pools. The intake is protected by cast-iron straining-plates, the vertical ones cylindrical, the horizontal ones semi-circular, with holes $\frac{1}{8}$ inch wide, by $2\frac{1}{2}$ inches long.

This intake was further covered by copper-wire gauze, 40 strands to the inch. The latter was, however, too fine. The weir is provided with a waste sluice to empty the pond.

The only difficult part of the work was the gorge. Here it was not practicable to make a road good enough for wagons the whole way along the track. The "camp," 1 mile from the intake, was accessible to wagons in dry weather, and for $\frac{3}{4}$ mile above the camp, and a $\frac{1}{4}$ mile below it the track was also fairly accessible. But the first $\frac{1}{4}$ mile from the intake, and the 2 miles in the gorge were more troublesome. A good bridle-path was, however, made most of the way near the pipe-track, and along this the pipes were carried in small carts or sledges. From the lower end of the gorge, which is $3\frac{1}{4}$ miles from the intake to Port Elizabeth, wagons were able to approach the track everywhere.

The pipe-line crosses the principal, Van Staaden's, stream, three times, the pipes being buried in concrete under the bed of the river. Some side-ravines were crossed by laying the pipes on pillars 18 feet apart, one pipe being supported on the two others, which latter rest on concrete saddle-blocks on concrete piers. A ravine with rather steep banks was crossed by means of a wrought-iron bridge with concrete piers. At certain points the pipes are carried along the faces of precipices by aid of iron brackets let into the rock. As there is no frost to speak of, it has not been thought necessary to cover the pipes, except where they might be damaged by falling rock. The pipes being always full of water, no special arrangement appears to be needed to provide for expansion, and no inconvenience or leakage has been experienced from this cause. The pipes are, as a rule, laid with the sockets pointing up-hill, the depth of the top of the pipe below ground being 15 inches, except where wagons are likely to come, where the depth of cover is 18 inches. Joint-holes of ample size were excavated for each socket.

Sluice-valves, to isolate portions of the main, are placed about every mile, and behind every sluice-valve a relief-valve is fixed. Air-valves are inserted at all important summits, and waste-valves at all important depressions. Pipes of short length, called access-bonnets, specially strengthened, and provided with lids bolted on them, are supplied to allow of scrapers being hereafter inserted in the main. These are placed about 3 miles apart. No man-holes have been left for them, as it is hoped that scraping will not be required for many years, and, at any rate, it is desirable to postpone it as long as possible, as scraping will have to be frequently executed when it has once been commenced.

Considerable extra expense was incurred in the gorge in order to protect the pipes against the loose stones or rocks that might fall on them, and along the pipe-track an extra depth of excavation was frequently adopted in order to protect the pipes against damage by ox-wagons, which in South Africa are not scrupulously kept to the road-tracks.

The break-pressure tanks are 11 feet square, rather less than 6 feet deep, and made of Portland cement concrete. The supply to them is given through a valve regulated by a float, the discharge from them starts with a trumpet-mouth casting. It was found that the float was disturbed by the eddying of the water as it passed out through the main, and the floats were enclosed in timber boxes. Each tank has an overflow-pipe in case the float-valve should not shut perfectly tight. The order of fittings at a break-pressure tank are 1, a relief-valve; 2, a sluice-valve; 3, an access casting; 4, the regulating valve; 5, a sluice-valve on the main below the tank; 6, another access casting below. There is also a sluice for letting the water out of the break-pressure tanks without discharging it down the main. A bypass was temporarily laid round the break-pressure tanks for the purpose of getting greater pressure when testing the main.

The pipes are laid, as far as practicable, in straight lines, with bends where a change of direction was unavoidable, no "swagging" being allowed in the horizontal plane. In the vertical plane swagging was permitted to the extent of 2 inches in each pipe-length, but any further deviation was provided for by the insertion of a bend. Seventy-seven curves were required in the first 3 miles, with an average deviation for each curve of 18°. From 3¼ miles to the service reservoir, a distance of 22½ miles, only fourteen curves were used, with an average deviation of 12°.

Special care was taken in calking the pipes. The front of each joint at the time of running was closed with a clip, which was so bevelled as to leave a ring of lead outside the socket. This ring of lead was driven as far as possible into the joint with tools of different sizes, and until the fringe of lead dropped off of itself. The workmen were not permitted to detach either the fringe of surplus lead, or the "head" where the joint was run, in any other manner. It was found necessary to padlock all the man-hole- and valve-covers, otherwise wagoners and other persons tampered with them in order to get a supply of water. The main was tested in lengths of about 1 mile at a time; for this purpose gauges were screwed on and high pressures obtained by shutting the valves rapidly.

The first pipes were removed from the beach in June 1879; some delay was caused by the necessity for cutting the many cracked pipes, and by extra work in the gorge; but by the end of 1880 the main was tested for the service of the town, and distribution commenced with the year 1881.

The actual amount paid under this contract, including extras, was £33,487. The work was carried out under the personal superintendence of Mr. J. C. Mackay, Assoc. M. Inst. C.E., son of Mr. John Mackay, the contractor. After the first few months Mr. North took no part in the contract.

Contract (iii.).

Contract (iii.) was let to the Glenfield Company, Kilmarnock, who manufactured and tested all the valves and fittings used both for the main and for the distribution, and delivered them on shipboard in Great Britain.

The relief-valves, Fig. 4, are partially balanced double-beat valves, with gun-metal beats on both valve and seating. Instead of being weighted by means of a spiral spring, as is frequently done, a special modification was introduced. This was at the suggestion of Mr. Wicksteed, who wrote (September 5, 1878) as follows:—

"It has occurred to me that by making the lever out of a bit of spring steel, the necessary sensitiveness might be given to the valves without the intervention of spiral springs, which, in addition to being more expensive, are, it appears to me, more awkward things to deal with, being liable to scrape against the sides of the chambers, unless very cleverly set. My experience in bicycle-riding has given me considerable faith in such a spring."

The beats as originally designed were too large, and were filed down. These relief valves work fairly well, but there is still much room for improvement. After having relieved pressure, they seldom come tight down on their seats without a tap from a stick; and when not brought into use for some time, they require a greater force to open them than when they are quite clean.

The regulating-valves of the break-pressure tanks and service-reservoir are also, as will be seen from Fig. 5, double-beat valves, and are as nearly balanced as practicable. These work well, with the exception that there is a tendency of the nut at the bottom of the spindle carrying the valve to work loose. The floats are of copper and are tinned, to prevent the formation of copper oxide.

The sluice-valves are of the usual pattern, with the exception that beneath the stuffing-boxes the spindles have shoulders working tight against a coned gun-metal bush let into the casting, so that the stuffing-boxes may be packed while the valves are under pressure. It is very important that the sluice-valves should not have too quick a motion; otherwise pipes may easily be burst by a careless turncock. The sluice-valves on the main are each protected by a relief valve; but the scouring, or waste-valves, may give a very serious shock to the main if shut down too quickly. In fact, an hotel-keeper, wishing to entertain a picnic party in the gorge, got possession of a valve-key, and turned on the waste valve at the lowest point of the gorge over 300 feet below the intake. But he shut the valve down too quickly, and a burst pipe was the consequence.

The air-valves used are a modification of Messrs. Bateman and Moore's pattern (Fig. 6). The smaller, or high-pressure valve, is kept distinct from the larger one, and is provided with a small cock, so that should it get out of order, either from dirt in the hole or any other cause, the cock can be shut and the valve examined and put right without emptying the main.

The fire-plugs or hydrant valves (Fig. 7) are generally of Messrs. Bateman and Moore's pattern, with slight modifications, except on the mains, where they are worked by rack and pinion.

Several kinds of balls were tried both for air-valves and fire-plugs. Gutta-percha balls with cork cores do very well for low pressures, but are apt to be squeezed out of shape by high pressures. In one case a gutta-percha ball was squeezed through a hydrant by a pressure equal to only 150 feet of head. Possibly if the cork core were smaller this would not happen. For high pressures, wooden balls with a coating of vulcanite were used, but much trouble has been experienced with these in consequence of the water penetrating through some pin-hole in the vulcanite, and permeating the wood so that the ball becomes too heavy to float.

The meters used are Kennedy's, and were chosen partly on account of the measurements being absolute and not inferential; and also because, with the aid of duplicate parts sent out with them, they may, if out of order, be repaired by any intelligent mechanic.

Kennedy's self-closing, waste-preventing public taps were used. The sizes and construction of the taps were modified to suit the intended pressures. The weight closing the tap is attached to the wheel by a spiral spring, so that the tap cannot be injured by the

sudden dropping of the weight when there is no water. The axis of the handle is of brass, working in a brass bush, otherwise there is a tendency to rust up. A hole with a screw plug was made inside the delivery-pipe, so that sticks that may be poked up by children can be readily pushed out.

The Glenfield Company also supplied a river-gauge which records continuously, on a cylinder moved by clockwork, the depth of water passing through notches in a weir just above the intake pool. There are three rectangular V-shaped notches.

Two rain-gauges of a special pattern were provided, and are now placed at two distinct points of the catchment area.

An evaporation-gauge is also established. This gauge consists of a circular pan, kept constantly full of water by a pipe from an accurately made cistern with a scale in it, the pipe being controlled by a ball-cock. The overflow-pipe of the evaporation-gauge discharges into another accurately made cistern also provided with a scale. Thus the evaporation is measured by the amount of rainfall, added to the amount of water drawn from the upper cistern, less the amount discharged into the lower cistern. It was originally intended to place this gauge on a raft floating on the intake pool, to be held in position by hinged rods attached to the weir, but this was not found practicable on account of waves, and a special tank was constructed in a safe position below the weir. The tank is fed and kept at a constant level by a continually-running stream from the main, and the water in it is thus at the same temperature, more or less, as that in the intake pool.

This contract included also all the fittings for house services. As this contract was let before the distribution in the town had been designed, the quantities were only approximate, and in fact were largely exceeded. Moreover, fire-hose and other articles not included in the original schedule were supplied at the request of the Council. The total amount paid was £7,142.

Contract (iv.)

Contract (iv.), for the manufacture and delivery of the distribution-pipes in the town, was let to Messrs. Cochrane, Grove and Co. The terms of this contract were much the same as those for contract (i.), the pipes having to be delivered on the beach. A similar design of socket was used. The proportionate value of special castings to that of the ordinary pipes supplied was 16 per cent. The ordinary pipes were delivered for from £7 2*s.* 6*d.* to £7 5*s.* per ton; the special pipes for £10 15*s.* per ton.

The number of pipes cracked under the first contract acted as

a warning in this case, and the percentage of breakages among the ordinary pipes was only 4 as opposed to 32 per cent. under contract (i.). Several weak sockets were split in calking, through the founders having cast the socket with a core for the air-hole instead of drilling the air-hole after the pipe had been cast.

The sizes, mean weights, and proof pressures specified are as follow:—

Size.	Mean Weight.	Pressure.	Size.	Mean Weight.	Pressure.
Inches.	lbs.	Ft. of Water.	Inches.	lbs.	Ft. of Water.
10	532	300	6	266	400
9	532	600	5	238	600
9	448	400	5	196	400
8	448	600	4	161	900
8	378	400	3	112	900
7	308	400	2	49	900
6	308	600	1½	37	900

All the pipes laid were 9 feet long.

The total amount paid under this contract was £13,728. This was £1,047 more than the contract sum, for in consequence of the growth of the town the Council decided to lay more mains than originally specified.

CONTRACT (v.)

Contract (v.), for laying the distributing pipes and fixing the requisite valves, was let to Messrs. Getliffe and Frames, local contractors. As soon as the pipes, valves, &c., were laid, Mr. Wicksteed organised a strict system of testing the mains, so as to discover all weak pipes, or those that had been damaged by careless handling. The fire hydrants were also subjected to severe tests, stand-pipes being fixed to each hydrant, and then tugged about in imitation of the treatment they are liable to receive at fires. The result of this latter process showed that in many cases the contractors had very imperfectly screwed up the bolts of the flanges.

Special arrangements exist for introducing scrapers. At intervals a branch pipe is inserted causing the line of pipe to

deviate a short distance, and then continue parallel to its former course. The former line has a "dead end" closed with a blank flange or stopper. By removing the flange or stopper the scraper can be inserted.

An important question in arranging distributing pipes is whether a distributing pipe should be joined at both ends to the mains, where such a course is practicable, or only at the nearest end. The joining up "dead ends" was objected to, because, if this is done, the turncock may leave the sluice-valve along the principal line of supply shut, causing the street to be supplied by a roundabout course. This would, as a rule, not matter much were it not for fires, when a large supply of water is required. An argument against dead ends is that rust and silt tend to deposit in them, and they require frequent flushing, otherwise the water supplied to adjacent houses is occasionally coloured.

The working of the hydrants in the market square has given great satisfaction to the inhabitants, jets 90 feet high having been thrown from 1½-inch nozzles. The insurance companies largely reduced their rates for fire insurance immediately after the first exhibition of the hydrants. For fire-hose, in a comparatively small town where fires are fortunately not of frequent occurrence, and in a moderately warm climate, leather appears to be preferable to canvas, as the canvas is attacked by moths if it lies long in the stores, and india-rubber melts or becomes rotten in hot weather.

Fig. 8 shows the town and the distributing pipes with the pressure in the different districts. The original main comes in about the centre of the town, but under contract (v.) a second main was laid from the service reservoir to the north part of the town. There is also a separate service to the "south end," crossing the Baaken's river ravine, but as will be seen on the diagram this main does not start directly from the service reservoir. The total amount paid under this contract was £11,223.

Contract (vi.)

The contract for the house services is let annually. The Council provide all the fittings and sell them to the contractor at slightly over cost price. Where there are no meters, and as far as the pipes are subjected to high pressure, the fittings used must be those provided by the Council. No cisterns are required, the water being constantly "on." The mains are never tapped for house services, but distributing pipes are laid alongside the mains.

The distributing pipes have 4 inches of specially thickened metal near the socket for the insertion of ferrules. Stop-valves are placed on each house connection, being generally fixed under the foot-path.

With the view of apportioning the size of house service-pipes, some experiments were made on the discharge of lead pipes and fittings, and it was ascertained that the friction caused by the stop-taps was very great.

With a pressure due to 200-feet head of water, the following discharges were experienced:—

	Gallons per Minute.
Through a ⅜-inch ferrule	27·0
„ ⅜-inch ferrule, with 12 inches of ½-inch lead pipe and a ⅜-inch stopcock	6·7
The same, with 30 feet of ½-inch lead pipe	5·4
The same, with 30 feet more of ½-inch lead pipe	3·7
The same, with 46 feet more (106 feet in all) of ½-inch lead pipe	3·2

The enormous check caused by a high-pressure stop-cock is certainly marked, and it is worth considering whether a better form of cock cannot be devised, or whether it would not be advisable to use a stop-cock of larger pattern for a given size of lead pipe, a ½-inch cock for a ⅜-inch pipe, and so on. This would admit of smaller lead pipes being used.

Compression-couplings were generally used for stop-cocks, and save much plumbing, but they are not so suitable for bib-cocks on account of the rough usage the latter frequently suffer. The contractor charges the householder according to a schedule in his tender, and the accounts are countersigned as correct by the waterworks inspector or municipal officer.

The weights of lead piping used are as follow:—

Size.	Per lineal yard.
1½ inch.	33 lbs.
1¼ „	25 „
1 „	15 „
¾ „	11 „
⅝ „	9 „
½ „	7 „
⅜ „	5½ „

The lead piping was all imported by the Council, and is supplied to the contractor at fixed prices.

CONTRACT (vii.)

The contract for the service reservoir was let to Mr. John Mackay, the contractor for (ii.), for £10,987; but, chiefly owing to the rock below the foundations, a sort of quartzite, not proving so solid as was expected from the trial pits, this amount was largely exceeded, the total cost having been £15,392. The site of the reservoir is shown on drawing No. 8; it is about 2 miles north-west of the town hall.

The reservoir, as will be seen from Fig. 9, is built in two portions, either of which can be used without the other. The capacity is 1,250,000 gallons. The whole was executed in Portland cement concrete, in the composition of which great care was taken. The stone on the spot was rotten, and most of the stone used was brought from more than $\frac{1}{4}$ mile distant, for which an extra price was paid. It was broken in a crusher worked by a steam-engine, then spread out in open boxes 20 feet long by 5 feet broad, set at a slight inclination, exposed to a strong jet of water, and turned over and over until all dust and fine soft sand was washed away. The sand was brought by bullock-wagon a distance of $3\frac{1}{2}$ miles. It was also thoroughly washed in a similar manner to the broken stone.

A great advantage was gained through the main being finished before concreting commenced, as there was abundance of water under a head of nearly 200 feet, for washing the sand and stone, mixing the concrete, and wetting the walls. The last point was very necessary, as the work was carried on in hot weather, and during most of the time a dry land-wind was blowing. The bottom was so irregular that the Author has not shown it on drawing No. 9. In fact, it was measured by keeping a strict tally of the cement and other materials used. The foundation was brought up to 6 inches below floor level, when a double coat of tar was put on, and then the final 6 inches. The proportion generally used in the concrete was 1 part of cement, 2 parts of sand, and 4 of broken stone. The materials were turned over once dry, and three times after being wetted; the mixture was then thrown into position with shovels, and carried up in 6-inch layers. The surface of each layer was well roughened with a pick, and swept and washed with a strong jet of water before the next layer was put on.

Instead of rendering the inside surface, arrangements were made by which the innermost bed of 6 inches of the walls was made of specially good concrete. This inner coat was toothed into the

main wall, and was carried up *pari passu*, the layers at the same level being put in at the same time, so that the whole forms one wall.

The main walls, including buttresses and centre division-wall, were built first, then the 18-inch walls supporting the roof, and subsequently the arching. The spandrils and haunches of the upper arches are of concrete, made with a somewhat less proportion of cement (1 to 9½).

The roof is covered with 8 inches of soil, and has been sown with grass seed; before putting on the soil, the surface of the concrete was grouted with liquid cement. The total quantity of concrete, without the foundations, was 3,538 cubic yards, which was paid for at an average price of £2 5*s.* per cubic yard. The work was done chiefly with Kafir labour, each labourer getting 4*s.* per day, without rations.

Close to the service-reservoir, an underground meter-chamber was constructed, holding a pair of Kennedy's meters, either of which can be worked independently of the other. The meter-chamber is provided with travelling hoisting-gear for removing the covers.

IV. Conclusion.

It has been a great advantage to this work that there were no old waterworks requiring to be adapted or fitted in, for the insignificant Shark's river supply was not taken into account. The system is, or should be, a very complete one. The water is extremely good; it is very soft, and contains no ammonia or lime, the only ingredient being common salt, and that only in a minute quantity.

No estimate has been made as to the quantity required per head of the population, as the water is at present somewhat lavishly used for gardens, and even for irrigating paddocks.

Possibly it may be desirable hereafter to construct a storage-reservoir either at Parkin's Vley (22½ miles), or in the mountains above the intake; and perhaps filter-beds may be constructed. Hitherto neither storage nor filtration have been thought necessary.

The total cost of the contracts given above is £118,673. In addition to this the Council had to pay for the preliminary surveys, the Customs' duties of 11 per cent. *ad valorem* on pipes under contracts (i.) and (iv.), amounting to £3,754, the customs duty and freights on articles obtained under contract (iii.), amounting to £1,609, and the cost of testing. The cost of supervision in the

colony, including engineers, draughtsmen, and inspector's salaries, office and travelling expenses, and the cost of the inspection in England, amounted to £7,297. A deduction must be made for the sale of fittings to the contractor under contract. With these additions and deductions, the total cost up to date, the Author is informed by the Town Clerk, has been £130,000.

The construction of these Waterworks has aided the expansion of Port Elizabeth, numbers of houses of moderate size having been built on "the hill." Had the works not been carried out, extension must have been limited to the low ground where the surface springs and the Shark's river give a scanty supply.

The Paper is illustrated by several diagrams, from which Plate 5 has been prepared.

(*Paper No. 1895.*)

"The Water-Supply of Peterborough."[1]

By JOHN ADDY, M. Inst. C.E.

PETERBOROUGH, on the Nene, and in the water-shed areas of that river and the Welland, was incorporated as a municipal borough in 1874. Previously to the incorporation, the Improvement Commissioners, as the urban authority, urged by frequent zymotic invasions, by the too obvious presence of organic impurities in the water, derived from shallow wells, public and private, as the sole source of supply,[2] and frequently by long periods of absolute water-dearth, had been compelled to consider the advisability of providing water from some extraneous and abundant source; but no active initiatory steps had been taken.

The Corporation, however, on its establishment determined to introduce an abundant water-supply and a new system of drainage simultaneously; and accordingly, in August of the same year, the Author was instructed to prepare schemes for both purposes. The

[1] The discussion upon this Paper was taken together with that upon the two preceding ones.

[2] As an example of Peterborough waters at this time, take the following:—

ANALYSIS of WATER from TOWN PUMP, PETERBOROUGH. JUNE 11th, 1873.

Expressed in parts per 100,000.

(*From Sixth Report of the Rivers Pollution Commission*, p. 88.)

Total solid impurity	213·800
Organic carbon	0·321
Organic nitrogen	0·113
Ammonia	0·000
Nitrogen as nitrates and nitrites	7·768
Total combined nitrogen	7·881
Previous sewage or animal contamination	77,360·000
Chlorine	22·100
Hardness, Temporary	27·300
„ Permanent	64·300
„ Total	91·600

REMARKS.—Clear. Slight saline taste.

water scheme described in this Paper is the result of these instructions.

An exhaustive examination of all the sources available in the neighbourhood of the city revealed but two, the river Nene and the Marlstone rock of the Lias formation, that promised to yield a supply adequate in quantity, while, even of these, the former failed to meet the requirements in point of quality. The latter, the Marlstone rock, underlying the sands of the middle Lias, would be reached, it was expected, at a depth of about 150 feet in the neighbourhood of Castor, a village about 5 miles from Peterborough. At Northampton, a well sunk into this bed was supplying 864,000 gallons a day, and geologists expressed the opinion that a similar supply could be acquired near this village by boring. This was, therefore, mentioned in the report to the council as a possible source; but the Author felt it necessary to seek for a larger supply, and one that could be confidently relied on to produce an equivalent to the maximum prospective requirements of the borough. Such a supply existed at Braceborough, and was adopted by the Author, although lying at a distance of 10½ miles beyond the municipal boundary. The Corporation accepted the report, but determined to make a trial boring at Castor. This was commenced in January 1875, and proceeded at an average rate of 1·936 foot per diem, until on June 7th a depth of 286 feet 6 inches had been reached, at a cost of £338 16*s.* 6*d.*, when no large quantity of water having been found, the boring was abandoned, and attention given solely to Braceborough as the source of supply.

The Water and its Source.

The water is found in the Oolite formation, in the bed between the Estuarine Clays and the Lincolnshire Oolite Limestone (called locally "the water rock"), the former being the lowest stratum of the Great Oolite, while the latter is the uppermost member of the Inferior Oolite. One of the main branches or tributaries of the River Glen has cut its channel partially through the Estuarine Clays for some miles above Braceborough Spa. This channel may be said to be a groove cutting more and more deeply into the clays, as the river falls in its course, and thus continually approaching the limestone under it, which bears the subterranean waters, until a point is reached where the stratum of Estuarine Clays under the

groove, owing to its thinness, or perhaps "faulty" nature, can no longer form an impervious division, or resist the upward force of the imprisoned waters. This point occurs in the river about 2 miles, measured up its course, above Braceborough Spa, and from it to the latter place the river is studded with springs, throwing up water with such force as to show distinctly above the surface of the rapidly-flowing stream. These eruptions, appearing at first singly, and at wide distances apart, gradually reach a climax lower down at "the Caudles," and again at Braceborough Spa, at both which spots the beds of the river, and of streams and pools adjacent, seem to some extent riddled by the number of vents for these waters. Below the latter outpouring there appear to be no springs of note, and shortly afterwards this tributary joins the Glen, which then enters the alluvial formations of the Fens. The same vein of water is reached at Bourne by boring to a depth varying from 85 feet to 102 feet, the water at times rising to a height of 40 feet above the average level of the town, and by its natural pressure supplying even the upper stories of most houses there; but this pressure is subject to considerable fluctuations, and at other times fails to supply above the level of the ground floors. From the same town and source, Spalding also takes its supply from a boring 91 feet deep, and there are, besides, twelve other borings for private uses. In the district directly north from Bourne, and especially in that portion of it immediately skirting the Fen formation, the same vein has been tapped and rendered available by a number of borings, some particulars of which are given in the Appendix. Mention ought also to be made of the noted "Well Head" at Bourne, as a display of this water in the form of natural springs, yielding, when gauged in 1874, at the rate of 4,600,000 gallons in twenty-four hours. At Horbling, too, there is a natural spring of some note.

The area of this water-bed has not been in any way defined, but it is most probably conterminous with the particular strata to which it is confined, so far as those strata are continuous.

The water, wherever thrown up from this source, is clear, sparkling, palatable, highly charged with carbonic acid gas, and, at times, giving distinct evidence of sulphuretted hydrogen, but this rapidly passes off. Analyses of the water from this vein, collected from four different points of outflow, natural or artificial, are given below, and, as a series, they present features of some interest.

ANALYSES of OOLITIC WATER as SUPPLIED by RIVER, SPRINGS and BORINGS.
Expressed in parts per 100,000.

	I.	II.	III.	IV.
Water collected from . .	River Glen after great accession of spring water.	Springs forming Bourne "Well Head."	Bourne Water Works derived from a Boring.	Boring near Braceborough Spa, supplying City of Peterborough.
Date	April 24, 1876.	Nov. 22, 1873.	Nov. 22, 1873.	February 26, 1876.
Temperature, Fahrenheit	42°	51°	49°	52°
Total solid impurity .	39·100	42·920	42·760	40·500
Organic carbon . . .	..	0·104	0·217	0·089
„ nitrogen . .	..	0·020	0·047	0·025
Ammonia	..	0·000	0·000	..
Free ammonia . . .	0·010	..	..	0·000
Albumenoid ammonia .	0·042	..	..	0·002
Nitrogen as nitrates and nitrites	..	0·000	0·000	0·000
Oxidized nitrogen . .	0·340	..	..	..
Total combined nitrogen	..	0·020	0·047	..
Previous sewage or animal contamination .	..	0·000	0·000	..
Chlorine	1·350	3·100	2·100	1·950
Hardness—Temporary .	17·700	23·400	23·400	21·500
„ Permanent .	5·300	11·800	11·800	6·700
„ Total . .	23·000	35·200	35·200	28·200
Remarks	Very turbid	Clear and palatable	Clear and palatable	..
Analysed by . . .	Dr. Odling	Rivers Pollution Commission (6th Report)		Dr. Odling.

The fluctuations of pressure, under which this water appears, have been referred to in the case of the Bourne supply. At the well now supplying Peterborough, when there has been no draught from it, the water-level has varied from 9 feet above the ground-surface, to 8 feet below it, giving a range of 17 feet; while the normal height may be said to be 4 feet above the surface, or 56 feet above Ordnance Datum.

The ground levels at Peterborough, referred to in the same datum, vary from 15 feet as the lowest, to 50 feet as the highest point, and the mean level of the populated area is 37·19 feet approximately.

Thus from the minimum water-level, given above, to the lowest level of the city, there is a fall of 29 feet, while to the highest point there is a rise of 6 feet, and to the mean level again a fall of 6·8 feet. It should be remarked, however, that the water-levels given above are approximate only,—the results of but limited observation, and it is extremely probable that the level 44, stated as a minimum, will be found, after some years' further registration, to be considerably above the actual minimum.

General Description of Scheme.

The works consist of :—

1. A well.
2. Two pumping-engines, boilers, and the buildings for their reception.[1]
3. A rising main from the engines to a reservoir.
4. A reservoir on Obthorpe Hill, distant from the engine-house in a north-easterly direction about 7 furlongs.
5. A supply main from the reservoir to Peterborough.
6. Distributing mains and services in Peterborough.

The relative positions of these several works will be seen on Plate 6, Fig. 1, and their actual connection can be gleaned from the following outline :—

The water, supplied by the well, is raised from it, and discharged into the town by the engines, any excess over the consumption being further raised and passed into the reservoir, giving the necessary working head, and forming a stored supply for use when the engines are not at work.

The Well and Borings.

The first boring at Braceborough was made at a point about 30 yards from the stream, a branch of the Glen, and at about 110 yards in its course below the Spa. After passing through the surface soil and alluvial gravel and clay, the Estuarine bed was reached at a depth of 16 feet, and was cut through to a further depth of 12 feet, when the water rushed up in large volumes, to 15 feet above the surface on September 6th, 1875. The yield on the 21st of September from the 4-inch bore was at the rate of 420 gallons per minute, giving a velocity of 770 feet per minute at 3 feet above the surface. The site being found unsuitable for permanent erections, a second boring was made about 30 feet from the present well, 600 yards north-east of the first boring. This was sunk to the "water rock," and an abundant supply proved to exist, while a good foundation for buildings was also passed through. The Corporation therefore bought 2 acres 1 rood 7 poles of land at this point, between the river and the Bourne

[1] 1 and 2 are situate on a plot of land purchased by the Corporation, and distant in a north-easterly direction about 3 furlongs from Braceborough Spa.

and Essendine Railway, with right of way to a neighbouring public road.

Well-sinking was commenced in February 1877. Owing to the large quantity of water met with, cast-iron cylinders of 5 feet 6 inches internal diameter, and in lengths of 7 feet, were substituted for the brick steining originally proposed, and were sunk to the surface of the "water-rock" at a depth of 50 feet. The upper portion of the well is constructed of cylinders 7 feet in diameter, in 5-feet lengths, which are continued above the surface, and completed by a domed iron covering, furnished with a manhole affording admission to the interior. The two sets of cylinders, which are connected by an angle-iron ring, and a concrete packing, are of 1-inch metal, and their joints are formed, in the usual way, by means of internal flanges bolted together. Borings were then made through the flaky surface (called locally "kale") of the rock, when the water rapidly filled the shaft, and the well was thus practically completed, having been eight months in course of construction. The total cost was £955 5*s*., or at the rate of £18 18*s*. 3·8*d*. per foot of depth, the extra works having added to the amount of the original contract at the rate of 12·38 per cent. Mr. Thomas Hinson, of Bourne, was the contractor for the well-work, and also for the borings at Braceborough and Castor.

Pumping-Station.

One block of buildings contains the engine-house, boiler-house, and stores department. Its extreme length is 114 feet 9 inches, and breadth, excluding chimney shaft, 44 feet. The buildings are substantially erected of brick, with stone facings, and are covered in with iron-trussed roofs close-boarded and slated. A siding from the Bourne and Essendine branch railway serves to connect the site with the Great Northern railway system. The contractor for these works, and at the same time for the reservoir, afterwards described, was Mr. John Coker, of Ryde, Isle of Wight.

Engines and Boilers.

Two beam-engines are provided for raising, supplying, and storing the water, each driving two pumps, and capable of delivering 750,000 gallons in twelve hours, when working at a speed of eighteen revolutions per minute, that quantity being the daily supply required for an assumed population of 25,000, receiving 30 gallons per head.

The pressure in the air-vessel, against which this volume of water was to be raised, was specified to be 108 lbs. to the square inch, a large allowance of surplus power being provided to cope with the extended range of mains and works, which it was assumed would be called for when the extra urban districts should take the supply, which may be said to be reserved for them. The effective pressure, for the town supply alone, when pumping over the stand-pipe, is 52 lbs. to the square inch, and 34 lbs. when simply throwing water to the reservoir-level. The cylinders of the engines are 32 inches in diameter, and the stroke is 6 feet. The pumps, of the bucket-and-plunger type, are each 17½ inches in diameter, the plunger diameters being 12⅜ inches, with a stroke of 3 feet.

The two boilers, of the "Galloway" type, are each 26 feet long, with a diameter of 7 feet.

All the arrangements, both of engines and boilers, as well as of the buildings, have been made with a view to the necessity for enlarging and extending the works at some future time, and for doing so with the minimum interference with the existing works.

Messrs. W. and J. Galloway and Sons, of the Knott Mill Iron-works, supplied and erected the engines and boilers at a total cost of £9,000. For the main features of the design of these particular works the Author was indebted to Mr. A. Kinder, whose valuable assistance, also, in working out the details of the whole scheme he may perhaps be permitted, at the same time, to acknowledge.

Delivery-Main and Main Supply-Pipe.

The pumps discharge into an 18-inch cast-iron delivery-main, which conveys the water to the main supply-pipe, also 18 inches in diameter, at a distance of 1,563 yards from the pumping station. By the main supply-pipe, from the point of junction with the delivery main, the water is sent either southwards to the city for immediate use, or, as a surplus and reserve, is passed northwards to the reservoir, at a distance of 630 yards. The total length of the 18-inch main supply-pipe is 20,532 yards, and this extends a distance of 958 yards within the borough boundary. To carry the bulk of the water to Westgate, which may be taken as approximately the centre of the inhabited area, and as the actual centre of distribution, a 16-inch main, 2,449 yards in length, is laid, forming an extension of the 18-inch main. There is thus a total stretch of 24,544 yards, or 13·95 miles, serving to connect the

source of supply and the elevated storage with the principal point of distribution. It may be of interest to state, that of that length 4,590 yards have been laid in private property, and the amount of compensation paid, or about to be paid, to the owners and occupiers, increased the cost of the works in those lands by above 11 per cent. The main, for the remainder of its length, follows the high road (the Lincoln Road) to Peterborough, on its way passing through, or in the immediate neighbourhood of, the town of Market Deeping, and the following villages, possessing in the aggregate a population of between six thousand and seven thousand inhabitants:—viz., Baston, Langtoft, Deeping Gate, Deeping St. James, Northborough, Glinton, Werrington, and Walton. The Corporation has the power of supplying water to these districts, and has made provision for so doing in all cases. Up to the present date, however, the dread of additional rates has been sufficiently strong to counteract the efforts of those desiring wholesome water, and no request for a supply has been made by any local authority acting on behalf of these populations.

The mains were laid, in the straight sections, with pipes 12 feet long, with bored and turned joints, the jointing medium being anti-corrosive paint; in other lengths the ordinary lead-joint was used. The average relative weights, and costs for the two methods of main-laying, are stated in the following Table:—

COMPARATIVE COST, from ACTUAL WORK, of 18-INCH and 16-INCH MAINS LAID (1) with LEAD JOINTS and (2) with TURNED and BORED JOINTS.

Per lineal yard.

Description of Mains.	Weight of Pipes.		Price per Ton.			Cost of Pipes.			Cost of Excavation, &c.		Cost of Leading, Laying, Jointing, &c.		Totals.		
	In lbs.	In Tons.	£.	s.	d.	£.	s.	d.	s.	d.	s.	d.	£.	s.	d.
18-inch main— (1) with lead joints	452·63	0·20207	5	15	0	1	3	2·86	2	9·50	3	0	1	9	0·36
(2) with turned & bored joints	451·41	0·20152	6	0	0	1	4	2·19	2	9·50	0	9	1	7	8·69
16-inch main— (1) with lead joints	401·80	0·17938	5	15	0	1	0	7·54	1	10·36	2		1	4	5·9
(2) with turned & bored joints	405·36	0·18097	6	0	0	1	1	8·59	1	10·36	0	11·35	1	4	6·30

An analytical statement of the entire cost of these mains, it is believed, will also be of some interest, and is given below:—

DETAILED and PROPORTIONAL SUMMARY of COST of 18-inch and 16-inch MAINS.

18-inch mains.

—	Total Cost. £. s. d.	Cost per Yard. £. s. d.	Parts per 1,000.
Main-laying. 1. Pipe-laying	4,987 7 9	0 4 6·17	150·07
Main-laying. 2. Work in connection with valves and fittings	193 15 0	0 0 2·11	5·83
Main-laying. 3. Special work	599 10 11	0 0 6·51	18·04
4. Pipes	26,289 11 2	1 3 9·56	791·05
5. " special	200 7 11	0 0 2·18	6·03
6. Valves and fittings	219 3 9	0 0 2·38	6·60
7. Compensation	743 16 0	0 0 8·08	22·38
Total cost	33,233 12 6	..	1,000·00
Total cost per lineal yard		£1 10 0·99	

16-inch mains.

—	Total Cost. £. s. d.	Cost per Yard. £. s. d.	Parts per 1,000.
Main-laying. 1. Pipe-laying	434 9 0	0 3 6·58	134·79
Main-laying. 2. Work in connection with valves and fittings	48 13 6	0 0 4·77	15·10
Main-laying. 3. Special work	11 13 2	0 0 1·14	3·62
4. Pipes	2,553 19 6	1 0 10·29	792·41
5. " special	118 14 8	0 0 11·63	36·84
6. Valves and fittings	55 11 0	0 0 5·44	17·24
7. Compensation	..	..	..
Total cost	3,223 0 10	..	1,000·00
Total cost per lineal yard		£1 6 3·85	

The positions of the valves and other fittings are shown on Fig. 2, as are also the various obstructions in the form of railways, rivers, drains, &c., on the direct line of route. At the first river crossing, that of the Glen, the pipes, in duplicate, were laid under the river bed, encased in concrete. In the other cases simple expedients were adopted; but, it is perhaps necessary to explain that, in these low-lying lands bordering on the Fens, the water-courses, drains, and culverts cannot be interfered with, and the pipes must therefore be carried under their beds, in the greater number of cases; many and comparatively abrupt changes of gradient were thus caused.

Mr. Miles Barber, of Barlborough, Derbyshire, was the contractor for pipe-laying, as well for these mains as for the smaller

distributing mains in the borough; Messrs. Cochrane, Grove and Co., of Middlesbrough-on-Tees, supplying all pipes and special castings required, and Messrs. Alley and Mac Lellan, of Glasgow, the valves and fittings.

The Reservoir.

The reservoir is constructed on the summit of an eminence called Obthorpe Hill, a rounded, denuded, mass of Oxford clay, capped with boulder or drift clay, about 7 furlongs in a north-easterly direction from the well, and at a distance, measured along the mains, of 2,193 yards from the main inward pumps of the engines. The site is at a greater elevation than any ground in the immediate neighbourhood, the summit level being 160·2 feet above Ordnance Datum.

The reservoir is constructed in part above ground, the floor having a level of 147·7, and the top-water a level of 163·7 feet, the depth of water stored to overflow-level being 16 feet. It is rectangular in plan, with an interior length of 120 feet, a breadth of 89 feet 6 inches, and a storage capacity of 1,000,000 gallons, nearly; and it may be concisely described as consisting of an inner shell of brickwork, encased in concrete, and made waterproof by an outer shell of puddle. The central roofing is formed of segmental brick arches, springing from 18-inch transverse walls, built with arched-over openings, leaving piers of 2 feet 3 inches by 1 foot 6 inches. At the ends the covering arches run longitudinally, springing from flange or wing walls, built at right angles to the end walls. The floor is of concrete, with a top dressing of cement. A central longitudinal wall, carried up to a height one-fourth of the maximum water-depth, enables one-eighth of the total capacity of the reservoir to be in use for storage, while the other section can be cleansed or repaired, and, to secure the same object, the terminal fittings of the delivery- and supply- mains are provided in duplicate. A standpipe, carried to a height of 53 feet above the floor, secures additional head. The height of water in the reservoir is telegraphed to the engine-house, and there shown, by a water-level indicator, supplied and fitted by the India Rubber, Gutta Percha, and Telegraph Works Company, of Silvertown. The cost of this section of the work was £7,356 12*s.* 9*d.* Figs. 3 and 4 show the reservoir in plan and sectional elevation.

MEANS OF DISTRIBUTION.

Within the borough the water is distributed by a system of mains, so laid out as to meet, so far as is practicable, the following principles:—

1. A sufficient constant supply, delivered under a sufficient and practically constant head, throughout the whole area to be supplied.
2. Ample provision to meet extended requirements and supply, under the same conditions as in the first essential: (*a*) within the area originally supplied; (*b*) outside that area, but within the urban limits; and (*c*) outside or beyond those limits.
3. An arrangement of the mains and valves, within the area to be supplied, that shall permit of the whole scheme being worked, and the normal supply given, independently of any one principal main, or length of principal main.
4. A continuous circulation of water in the mains.
5. Ample provision of means for rendering the water easily available for the extinction of fires, for sanitary, and for all other purposes.
6. Moderate first cost.
7. Economy in the ultimate working of the whole scheme.

In accordance with these principles, the trunk-mains, by their comparatively large size and extent of ramification, are rendered capable of delivering the maximum supply demanded by present and probable future requirements, and at a practically constant head, while in case of the disuse of one of the principal northern mains, another can be worked as a substitute. Rider-mains are attached to all these larger mains, and provide for the strictly local supply of houses and hydrants.

The branch-mains between the trunk-mains, as well as those and the service-mains feeding from them, but lying outwards and towards the extreme bounds of the area at present taking water, have in like manner been suited in their carrying capacities, not only to the existing demands upon them, but also to the requirements of the scheme as a whole, and further to the probability of an extended supply.

The inter-connection of the entire system of mains has been made as thorough as practicable, and consequently the whole central scheme, under proper management, admits of, and assists in, a constant circulation. In the south and north-east districts a circulatory system has not been so thoroughly obtained, owing to

the partial severance from populated areas; but in each case this, at present necessary defect, will be remedied as the population increases, and the mains are extended and inter-connected with those of neighbouring areas.

The water, thus conveyed into all parts of the district, is made available, for sanitary purposes and fire-extinction, by three hundred and fifty-four Bateman and Moore's patent ball-hydrants, placed, on the average of the whole area dealt with, in the proportion of one hydrant to every 103·32 yards of main.

Of the laying and fitting of the mains, it need only be said that the bored and turned joint, with anti-corrosive paint as a medium, was employed for all pipes (except the 4-inch, which were jointed throughout with lead) in the straight sections, to as great an extent, and in as extended lengths as could be conveniently done, the lead joint being used in curves, and with special pipes where required, but at the same time as sparingly as possible. Work of a special nature, however, was involved at the river-crossing, and at two of the railway-crossings.

The total length of mains within the borough, and exclusive of the 18-inch and 16-inch main supply-pipes, is 43,393 yards, and it is made up of four sections, as shown in the following Table, which gives the lengths and sizes pertaining to each section:—

Size of Mains.	Description of Mains.				Total Length of each Size of Main.
	Trunk Mains.	Rider Mains.	Branch Mains.	Service Mains.	
	Yards.	Yards.	Yards.	Yards.	Yards.
12-inch	1,234	..	402	..	1,636
10 "	835	..	..	..	835
9 "	2,827	..	..	..	2,827
8 "	2,680	..	..	..	2,680
6 "	..	..	3,209	265	3,474
5 "	..	..	8,631	788	9,419
4 "	..	9,940	8,663	3,919	22,522
Total length of each description of main	7,576	9,940	20,905	4,972	43,393

The entire cost of these 43,393 yards of mains within the borough was £16,654 1*s.* 1*d.*, a sum which was expended in three contracts (undertaken by the contractors, mentioned in describing the construction of the main supply-pipe as doing work of the same description) in the following proportions:—

	£.	s.	d.			Parts per 1000.
1. Main-laying and fitting .	4,949	8	4	equivalent	to	297·19
2. Providing pipes and special castings	10,867	11	8	„	„	652·55
3. Providing valves, hydrants, and all fittings . . .	837	1	1	„	„	50·26
Total cost . .	£16,654	1	1	„	„	1,000·00 parts.

House-Services.

The Corporation undertook the work of laying and fitting these services, between the mains and the property of consumers; the work upon the premises being executed by tradesmen, who must have qualified by signing an agreement to work in accordance with regulations issued by the Corporation, and who, after so doing, were "authorised" to carry out such work for the consumers.

Concluding Remarks.

The cost of the works in their entirety, and the expenditure upon each branch, with its proportional relations to the sectional, as well as the total outlays, are given in Appendix II.

From this Table it will be seen, that the total expenditure upon the scheme amounted to £87,568 4*s*., or about £4·127 per head, within the municipal boundary; but as the works have been, in their design and capacity, prepared to afford a supply to several districts lying outside that boundary, this capitation will be considerably reduced when their populations participate in the water. The Table also shows to what an extent a capital outlay may be influenced, by a source at a considerable distance from the area to be supplied, that outlay in this case being represented by the cost of the 18-inch mains (item No. 17, viz.), £32,489 16*s*. 6*d*. or more than one-third (0·371) of the total cost.

There can be no doubt that water from the particular Oolitic vein by which this scheme is actuated is destined, in the near future, to play a very important part in the supply of the Fen districts and their immediate surroundings. Already Bourne, Spalding, and Peterborough make use of this source for their public service, and the Peterborough works can, and probably will, supply several districts, lying either adjacent to their 18-inch main, or within moderate distances of it, or the borough limits.

A scheme prepared by the Author in conjunction with Mr. Richard Hassard, M. Inst. C.E., and for which Parliamentary sanction has been obtained, will provide, by its main, extending

from the source of supply at Braceborough to Sutton Bridge, a distance of $32\frac{3}{4}$ miles, for the supply of the numerous and important districts on, or adjacent to, its line of route, as well as for the centres of population represented by Sutton Bridge, Long Sutton, Gedney, Holbeach, Whaplode, Moulton, Moulton Chapel, Cowbit, Littleworth, and several others lying off its actual course. Quite recently, a boring has been made in Dunsby Fen, about 5 miles north-west of Spalding, and water, which rises above the surface, found at a depth of 170 feet. From the nature of the strata passed through, and from the circumstances under which the water was found, there can be scarcely a doubt that it springs from the same vein as that so generally reached in the higher districts; the peculiar interest attaching to this particular boring being, that it is the first, so far as can be ascertained, that has been made (at least successfully) in the Fens, and the fact that it may point to a partial, or general extension of this vein of wholesome and easily obtained water beneath Fen districts hitherto supposed to be cut off, by long distances, from any safe or constant supply.

The Author is indebted to Mr. John Wadsley, Contractor, Horbling, for much valuable information in relation to numerous borings made by him; and in Appendix I. this has been tabulated with additional particulars obtained from other sources. Mr. R. M. Mills, Chairman of the Bourne Waterworks Company, &c., Bourne, who, as a manufacturer of aërated water, distributes the Bourne water over the country, has furnished useful and interesting facts and figures in connection with the local supply, which the Author wishes here to acknowledge.

Water was first given to the inhabitants of Peterborough on the 1st of December, 1879, a constant supply having been provided since that date; and on the 1st of January, 1881, the management of the entire system was undertaken by the Corporation.

The Resident Engineers during the construction of the works were Mr. Alfred Bard and Mr. J. S. Moloney, B.A.

The Paper is accompanied by several drawings from which Plate 6 has been prepared.

[APPENDICES.

APPENDIX I.—PARTICULARS of BORINGS MADE in SOUTH

No.	Locality (working from Bourne northwards).	Size of Bore.	Depth of Bore.	
		Inches.	Feet.	Inches.
1	Bourne water works	4	93	6
2	„ „ Star Lane	5½ and 3	89	6
3	„ Great Northern railway station	4	90	0
4	„ supplying Spalding	6	91	0
5 to 15	„ private supplies	vary from 1 to 3	Feet. 85 to	Feet. 102
			Feet.	Inches.
16	Cawthorpe, private	4	110	0
17	Dyke	2	78	0
18		2 (?)	78	0 (?)
19		1½	..	
20	Morton	4	93	0
21	„	2½	93	0
22	Hanthorpe	4	168	0
23	Dunsby	4	105	0
24	„	4	120	0
25	„ Hall	4	112	6
26	„ Fen (about 5 miles N.W. of Spalding)	4 (?)	170	6
27	Rippingale	4	130	0
28	Graby	4 (?)	150	0
29	Pointon	3	87	0 (?)
30	Folkingham	4	300	0
31	Billingborough	3	87	0
32	„	3	87	0
33	„	3	95	0
34	„	6	87	0
35	Horbling	3	87	0
36	„	3	87	0
37	Swaton	4	200	0
38	Sleaford	4	120	0
39	„	4 (?)	120	0 (?)

LINCOLNSHIRE for WATER from the OOLITE FORMATION.

Results.	Strata, &c.
Water rose about 39 feet above surface.	
Water rose to 41 feet above surface, May 17th, 1880	Chamber, 4′ 6″; clay, 11′; blue rock, 6′; black clay, 4′; yellow clay, 3′; rock, 4″; dark clay, 8′ 8″; rock, 11′; chalky clay, 9′; hard rock, 9′; clay, 4′; soft rock, 3′; hard, close, tough, dark clay, 13 ft.; water rock, 3′.
Water rose nearly 30 feet above surface.	
Water rose about 40 feet above surface.	
Water in all cases would rise above surface.	
Water rose 12 feet above [surface.	
Water delivered above surface.	
Water rose 20 feet above [surface.	
" " "	
No water.	
Water rises above surface	Similar to No. 25.
" rose 7 ft. " "	" "
" " 9 ft. " "	Soil and clay, 6′; rock, 4′; blue clay, 46′: rock, 14′ 6″; blue, green and black peat(?), 35′; kale, 7′.
Water rises above surface. (Height not ascertained)	Quicksand, 21 ft.; blue clay, 47′; rock, 10′; blue clay, 10′; rock, 11′ 6″; blue and mixed clay, 12′; rock, 18′; green clay, 3′; light coloured clay, 3′; kale, 4′; blue clay, 20′; green clay, 5′; black peat, 3′; rock, 3′.
Plentiful supply by lift pumps	Similar to No. 25, but top clay of much greater depth.
No water.	
Water rose about 20 feet above surface . . .	Similar to No. 32.
Variable supply . . .	Particulars doubtful, but one stratum of rock was passed through, about 100 ft. in thickness.
Water rose about 20 feet above surface . . .	Sunk in well bottom 10 feet deep, then followed quicksand, 23′: blue clay, 14′; blue rock, 14′; blue, green and black clay, 26′.
Water rose 2 to 3 ft. above surface	Mixed clay, 37′; blue rock, 14′; blue clay, 4′; rock and kale, 4′ (plentiful supply from this); blue, green and black clay, 28′.
" " "	Started probably 10 feet below surface; then followed blue clay, 4′; rock, 4′; blue clay, 19′; blue rock, 14′; clay, 4′; rock and kale, 4′ (which afforded a good supply above surface); blue, green and black peaty clay and kale, 28′; kale, 8′.
" " "	Similar to No. 32.
" " "	Soil, 4′; gravel, 5′; rock, 6′; blue clay, 22′; blue rock, 14′; clay, blue, green and black, 34′; kale, 2′.
" " "	Similar to No. 32.
Water stands between 3 ft. and 4 ft. below surface.	
Water rises above surface.	

APPENDIX II.—SUMMARY and PROPORTIONAL STATEMENT of TOTAL EXPENDITURE.

No.	Items.	Total Cost. £.	s.	d.	Parts per 100,000.
1	Costs of provisional order . . .	307	5	1	350·87
2	" " opposing Peterborough and Braceborough water Bills .	733	9	11	837·63
3	Trial borings at Castor and Wilsthorpe	489	17	3	559·41
4	Charges, &c. in respect of loans .	1,543	1	11	1,762·16
5	Purchase-money of two plots of land, and costs in connection with the purchase	1,271	5	7	1,451·76
6	Contract advertisements . . .	23	1	6	26·35
7	Compensation payments . . .	814	8	6	930·05
8	Constructing railway siding . .	46	1	10	52·63
9	Well and fittings	955	5	0	1,090·86
10	Engine, boiler, and stores houses.	5,985	16	4	6,835·61
11	Engineer's cottage, &c. . . .	645	7	1	736·97
12	Roadway, fencings, &c. . . .	478	6	5	546·23
13	Engines, boilers, &c.	9,000	0	0	10,277·70
14	Reservoir	7,356	12	9	8,401·04
15	" castings and fittings .	495	12	10	566·01
16	Water-level indicator	49	0	0	55·96
17	18-inch mains (exclusive of compensation)	32,489	16	6	37,102·31
18	16-inch mains	3,223	0	10	3,680·61
19	Urban mains and fittings . . .	16,654	1	1	19,018·38
20	Engineering charges and expenses	5,006	13	7	5,717·46
	Entire cost of works . . .	87,568	4	0	100,000·00 parts

Discussion.

Mr. R. Rawlinson, C.B., said the Papers contained much useful information, that by Mr. Leslie being especially instructive, as detailing the growth of extensive works from small beginnings. In some of the earlier embankments the old principle of laying cast-iron mains beneath the embankment, with the valves on the outside, had been practised, and so far, he assumed that nothing serious had happened; but it was a condition in which pipes ought not in future to be laid, and one under which reservoirs ought not to exist. It might be instructive if he were to mention an unsuccessful work with which he had been connected. Twenty, or more, years ago he designed and constructed a reservoir for Swansea, in a valley about 8 miles from the town. The sub-basement was rock, part of the Millstone Grit formation. A puddle-trench, according to the practice of the day, was sunk in the rock, from 15 to 20 feet below the surface; and the bottom of the trench was coated with concrete, so as to prevent any weeping of the springs, or the access of water into it. Of course he was very careful in giving instructions for the proper arrangement of the puddle and of the bank, and two or three times between the commencement and the completion he induced the Corporation to give a higher price for the work to the contractor, so as to enable more care to be bestowed upon it. The reservoir remained for ten or twelve years practically tight. The outer half of the bank was drained from the puddle-trench, and there was a small gauge, over which the water that came from the outer portion of the bank percolated, and the volume of flow was not influenced by anything within. The rise or fall in the reservoir did not affect the outer spring-water for ten years. An autumn and winter of severe and continuous rain however occurred, and a leak from the outer part of the bank with discoloured water was established. It went on for two or three years, and it was ultimately decided to effect a repair, which was undertaken and completed by Mr. E. Cousins, M. Inst. C.E., at a cost of about £12,000. The work was effectually carried out by laying open the centre of the bank down to the bottom of the original puddle-trench. A fissure was found in the rock, with water rising, when it was bared, 12 or 15 inches above the surface of the rock, showing what had been the cause of the mischief. This water was conducted by a cast-iron pipe to the outer side, and the trench was

Mr. Rawlinson.

Mr. Rawlinson. made good by a mass of concrete. The bank again stood for some three years perfectly tight, but during the last autumn and winter, which had been excessively wet, a fresh leak had appeared near the place of the old one, but not in the place repaired. Any person who had studied the character of rocks geologically knew that valleys of denudation had been gradually wasted to their present form by the infiltering of water, the disintegration of rocks, and the washing away of the material; and he could only imagine that the excessive rains in the district had got into fissures above the site of the reservoir, had forced a passage through them, and come out in the veins of the rock in the puddle-trench. That excessive storm-water in Wales followed that course and did mischief of that kind on a very large scale he had seen demonstrated. He remembered a storm about the year 1846 occurring upon the Berwyn mountains, where water got into fissures of the rock and dug thousands of cubic yards of material out of the side of the mountain; in some cases the water left its old courses, and washed the *débris* down into the valley on the bank of the Dee, and buried the small village of Corwen up to the eaves of the houses. It was very unfortunate for Swansea that the mischief he had mentioned in connection with the reservoir occurred, but it taught him the lesson that if he had to begin *de novo* he should take care that any trench dug in rock should, by the use of concrete, be put beyond the possibility of water finding vent in the trench. Whether he should succeed in stopping all the vents that were covered by an embankment 500 feet in width he could not undertake to say. An engineer, in executing an earthen embankment, could not be too careful as to what he was dealing with, and he should minutely examine the sub-soil before the formation of the bank was commenced. He knew that some engineers had been greatly tormented with leaks from beneath earthen embankments, and it had been put on record that no reservoir, if it had a depth of more than 60 feet of water, ought to be constructed of earthwork. He did not, however, quite agree with that recommendation. Reservoirs much deeper than that had existed for many years. He had, on behalf of the Government, examined most of the reservoirs in Lancashire and in Yorkshire, and he had yet to see the earthen embankment that could be pronounced absolutely watertight. They had not, it is true, been leaking to a dangerous extent, but where there was an area of from 500 to 600 feet in width in a valley of the description he had mentioned, there were always more or less weeps or springs rising underneath; and if

the engineer was not exceedingly careful he would have some form of waste from them. That showed the necessity of a thorough examination of the site. There were however sites upon which an engineer should not attempt to make a large impounding reservoir, as on some portions of oolite, on portions of Millstone Grit, and of Mountain Limestone, because they were so liable to be fissured, and some of the fissures were not to be found until the catastrophe happened. Where Mountain Limestone existed to a large extent, entire rivers disappeared in fissures, to appear again several miles below the intake. There were some such rivers in England, and more in Ireland; and wherever Mountain Limestone existed there was that liability. If an engineer selected a stratum composed partly of alluvium, partly of shale, and partly of rock, he should not disturb the material upon the inside for making the bank; he should not open it out as a quarry, excavating to the fissures, which he knew had been done in some cases, as, for example, in the case of the Dale Dyke bank, which gave way with such fatal effect. The site for an impounding reservoir should be as perfect as possible, and the outer area should be drained, and the inner area should be left undisturbed, or be coated with concrete. He was inclined to think, however, that a puddle wall was a mistake, and if he had to begin again as a waterworks-engineer he should try and construct embankments without a distinct and separate puddle-wall. A puddle-trench, as at present constructed, was 12 or 15 feet wide at the bottom, tapering on two sides, 1 inch to 1 foot in height. The embankment was perhaps 1,000 or more feet in length, and 90 or 100 feet high, and the puddle-wall might be carried down some 50 to 60, or even 100 feet. If it were possible to strip from that puddle-wall the two supporting sides, what would be seen? A thin wall of puddle liable to twist, to bend, to warp, and to crack, with nothing to support it but the two masses of earthwork at the sides; the inner half alternately saturated with water and dry, as the reservoir happened to be full of water or empty; the outer half dry, except during rain. Under these conditions the puddle-wall became liable to cracks, which ultimately became leaks, sources of trouble, and at times of danger. All embankments subsided more or less, and there was a tendency in all puddle-walls to warp and so produce weak points. A young engineer often imagined that a very strong retentive puddle was the perfection of material to work with; but in reality the stronger the puddle the more dangerous it was. When a strong clay was worked by 60 or 70 per cent. of water into the

Mr. Rawlinson.

Mr. Rawlinson. condition of puddle, and the water wept away from it, the substance of the puddle must crack, and these cracks would never again heal. He had seen an embankment, with apparently the finest material in the shape of strong clay for puddle, with cracks large enough to admit his arm. If it was necessary to puddle, and the clay was too strong, it should be toned down by some material, such as gravel.

Some reservoirs had been made with by-washes far too small for the area above the embankment. The Dale Dyke reservoir had upwards of 4,000 acres of drainage area above it, and the by-wash was only some 60 feet wide. From experiments and examinations he had arrived at the conclusion that, generally speaking, a by-wash ought to be 3 feet wide for each 100 acres of gathering-ground, subject, of course, to some modification according to the character of the gathering-ground, the capacity of the reservoir, and the amount of rainfall. It was, however, only a rough-and-ready way of saying that there must be a capacious by-wash. In one of the great Edinburgh reservoirs the by-wash arrangement was 1 foot for every 40 acres. Where the area amounted to 10,000 or 12,000 acres, a young engineer, without much experience, had not the slightest conception of the volume of water that would come off in an excessive flood; but speaking in general terms, if the dry-weather flow was 1, measuring by gallons or feet for a dry summer, an excessive flood might be 500 or even 1,000; so that if there was not a sufficient by-wash area, the embankment must be in danger. On inspecting some of the Sheffield reservoirs after the catastrophe at Dale Dyke, he found that the water had been blown over and running down the outer slope. It had probably washed over in waves, and that was the most dangerous position in which an earthen embankment could be placed. If an engineer wished to keep at a high level the water of the reservoir during the dry-weather period, such arrangements should be made as would allow of the water being drawn down when a flood was coming on, and thus bring the impounded water to the lowest level.

With reference to the cost of service-reservoirs, he had stated on a former occasion[1] that for 1,000,000 gallons a first-class reservoir should be made for about £5,000. The cost of the reservoir at Port Elizabeth, he observed, considerably exceeded that amount, being £15,392 for 1,250,000 gallons, which he considered an enormous cost. The Peterborough reservoir had also cost considerably above

[1] Minutes of Proceedings Inst. C.E., vol. lxxiii., p. 45.

Mr. Rawlinson.

the rate he had mentioned. At the discussion to which he had alluded, he had spoken of a circular covered reservoir, which he thought might be made much cheaper than any of the square ones. Such a reservoir (Plate 7), 250 feet in diameter, and for 25-feet depth of water, holding 7,000,000 gallons, might be constructed at a cost of £28,000, or at the rate of £4,000 per 1,000,000 gallons. He had taken out the quantities very liberally, allowing £1 per cubic yard for walls of concrete; about £2 per cubic yard for the brick-work; the ironwork at a little under, £10 per ton; and 1*s.* 6*d.* per cubic yard for the excavation.

There were Indian reservoirs some centuries old, in which no puddle-trench and no puddle-bank had been made; but the material was carried to the site in baskets on the heads of the natives, and trampled down by men or by elephants, and so gradually became thoroughly incorporated. It was a question whether that was not a more sensible way of making an embankment. At all events, his opinion was that any earthen bank should be absolutely tight throughout, should in fact be all puddle-wall from base to top, as he thought there was no safety for that class of bank, unless the inner portion of the material at least was watertight throughout, as surface tightness by a covering of puddle would not answer.

With reference to the position of filter-beds, some were put close below the impounding reservoir, and then there was a conduit which carried the water of the town any number of miles that might intervene down to the service-reservoirs. Those service-reservoirs might be open, as in Dublin, or closed. In his opinion the filter-bed and the service-reservoir, wherever they were situated, should be side by side. The water should pass from the filter immediately into the reservoir, and the reservoir should in all cases be covered. The water should go from the service-reservoir into the services of the town, and be thence drawn out of the tap. He observed that in Edinburgh the rate of filtering was about double the rate allowed in London filters. This he considered a mistake, as the rate of filtering had a good deal to do with the character of the filtered water. He believed the London rate was a little more than 500 gallons per square yard in twenty-four hours, and he thought that was quite quick enough.

Mr. Baldwin Latham.

Mr. BALDWIN LATHAM had made numerous experiments, with a view to determine the stability of banks, especially when exposed on one side to water. He had operated upon a large number of materials to ascertain the percentage of water which they naturally absorbed. A reservoir embankment, forming part of the structure to resist the action of water, was often largely

Mr. Baldwin Latham. made up of water itself. The stiffest clays, as a rule, held the largest percentage of water. With the exception of rotten peat, clay held the largest amount; marly clays came next to the pure clays. In loamy soils the percentage of water they held varied from 35 per cent. by weight to 60 per cent.; the mixture, therefore, of sand with clay really limited the amount of water which it would naturally hold. It had occurred to him that the stability of a bank might be determined roughly by dividing the percentage of the water it would hold by weight by 12, which would represent the horizontal distance that should be given to a bank to 1 of vertical, in order that it might be absolutely stable; so that a clay soil holding 50 per cent. by weight of water should have an internal slope of 1 in 4; and sandy soils varying from 33 to 25 or 20, or even less, the rate of the slope of the inner side exposed to the water might be very much less. Of course, the rule referred to gave a scope within the angle of repose of the material itself. If young engineers wished to see the effects of different kinds of soil with regard to the angle of repose, he would recommend them to look at the railway cutting recently made through Park Hill at Croydon. The upper part of it was through the plastic clays, and the lower part through the Thanet sands overlying the Chalk. During the last winter the Thanet sand stood perfectly with its slope as originally constructed. There had been immense slips of plastic clay in the cuttings, which had been filled up several times, showing that the plastic clays had a much greater angle of repose than even 1 in 5. Some years ago he constructed an impounding reservoir in Oxford clay, and he found it necessary to make a slope of 1 in 5 before he could get the embankment to stand. It was a reservoir for irrigation purposes. With regard to the Gladhouse reservoir-embankment mentioned by Mr. Leslie, there appeared to have been some trouble with the slopes. He could not conceive that the mere mixture of too much water would produce the effect, unless the slope of the embankment was steeper than the angle of repose of the material. It was a matter of considerable importance in the construction of embankments that the slope of the reservoir should be well within the angle of repose. With reference to concrete puddle-walls, a few years ago he was engaged in a case where a reservoir had failed. He examined it after the failure, and found that instead of a puddle-wall, concrete had been introduced, and it had been a stipulation in making it, that the whole of the work was to be brought up in layers to a uniform level, when it was allowed to set. The con-

Mr. Baldwin Latham.

crete put in the layers was tipped from a considerable height, and as a natural result the large stones all sank to the face which had been already prepared, and the consequence was that at every jointing, when the reservoir was attempted to be filled, the water went through. He saw the material blown out, and it came out stratified in blocks at every bedding; so that even in the case of concrete great care was needed in the use of the material. If so much attention had not been taken to do this work remarkably well, the embankment would probably have stood. It was the great care observed in allowing every layer to set before commencing a fresh one, so that the work was not one homogeneous mass, that was the cause of failure in this case. Of course, as Mr. Rawlinson had pointed out, the puddle was very liable indeed to crack if made of pure clay. The slopes of an embankment ought to be protected with materials to prevent them cracking. It was well known that clay would crack in the dry season, and in the autumn a stick might often be put in 2 or 3 yards simply from the cracking of the material. When the water in the upper part of the reservoir had fallen considerably below its ordinary level, what was there to prevent the whole of the upper part of the puddle-wall from cracking in the same way? He had seen indications of puddle-walls cracking down to a considerable depth, and great care was needed when there was a sudden rise of water to have the openings properly filled up before the water got access to them. That, however, was not always possible. He might be permitted to mention the case of a covered service-reservoir constructed on an entirely new principle, by Mr. W. Ranger, at Croydon, holding 900,000 gallons. It had not a single internal support, and it was much cheaper than the reservoirs under discussion, the cost of this reservoir being £3,378 15*s.* 7*d.* It was constructed of a series of brick ribs, springing up from the bottom, meeting in the centre, with reverse arches, convex inside and outside, and the spandrels between the arches were filled in with earthwork. That reservoir had been in existence since 1850. It had a depth of 35 feet of water, and was 74 feet internal diameter, and it had never shown any sign of failure, except that in 1853 the clay covering slipped off, having been put on at too steep a slope. That reservoir was one of the cheapest and best ever constructed in this country. With reference to the failure of so many pipes, to which allusion had been made, it was no wonder that a pipe of that class should fail, having no bead or fillet at the end. Such pipes were extremely liable to crack in carriage. Yarn, he observed, was used in the jointing. He was

Mr. Baldwin Latham. happy to say that since he had been in practice he had never used an ounce of yarn in pipe jointing. All the pipes he had jointed were usually made with shallow sockets, first filled with cold rod lead, which was driven in with a calking tool, and molten lead was run in afterwards to complete the joint. In 18-inch pipes the depth of the socket was only 2½ inches, and the thickness of the joint not more than ¼ inch. He had never had an instance, even in a pumping main, where there had been the slightest weeping from the joints. With reference to the turned and bored joints in the Peterborough works, he could not conceive that a joint of that kind could be tight for any length of time, especially as it appeared to remain unjointed with lead. Where turned and bored joints were employed it was usual to form a lead joint as well. He had himself determined by experiment that with a covering 2 feet 6 inches thick of soil there was a variation of temperature of 33° in the material of which the pipe was constructed, and that, in a cast-iron pipe, meant that there must be a difference of length of a little more than a foot in every mile; and how a pipe was to keep tight under those variations of temperature, if it simply depended upon the mechanical fitting of joints of a conical description, he did not know. The slightest giving at any of those joints must lead to weeping and to a waste of water. If a pipe would not give way it must break. The spigot-and-socket pipe was originally introduced by Mr. Thomas Simpson, in the Chelsea Waterworks, on account of the failure that had occurred in the flanged joints, which it was found impossible to keep tight. The principle of the flanged joint and the principle of the turned and bored joint differed but slightly, and if one was imperfect the other could not be commended for use in waterworks.

Mr. Lewis. Mr. W. B. Lewis wished to congratulate the Town Council and the Engineer of Port Elizabeth for having carried out a rather troublesome work at a very reasonable cost. He had, however, certainly been startled to hear that the breakages of pipes had amounted to 32 per cent. When the works were projected and the contracts were advertised some contractors had consulted him about tendering, but the risks were so great that they thought it better not to tender. One of those risks, no doubt, was that of landing the pipes. There were at Port Elizabeth no quays or wharves to which lighters or other vessels could go; everything had to be landed in the surf upon the beach, but still the percentage he had mentioned seemed enormous. From 1868 to 1871 he had been engaged in the purchase and shipping to Calcutta

Mr. Lewis. of nearly 24,000 tons of pipes varying from 42-inch pipes, weighing 2 tons 9 cwt., down to 3-inch pipes. There were over 13,000 tons of 42-inch pipes. They had to be landed in the Hooghly by the ordinary lighters, and out of the total of 23,271 tons received only 1,144 tons were damaged, or a little under 5 per cent. Many of the damaged ones were used, and the total quantity required to make up the deficiency was 453 tons, or a little under 2 per cent. He had looked carefully through the returns to see if any general conclusions could be drawn to account for the different breakages, but of course in the case of conveyance by ship there were many contingencies that had nothing to do with the pipes themselves. One vessel might meet with very bad weather, while another might sail in calm seas, and the results would of course be very different. In the case of the pipes he had mentioned at first a band of iron was put round the ends in the manner stated in the Paper; but it did not hold good even while the pipes were being loaded at Glasgow. A similar result took place at London and the plan was abandoned as unsuccessful. The large pipes were of course very troublesome to ship, but the total damage in their case was only 6 per cent. Of the 18-inch pipes there were 846 tons, and the damage was 11 per cent. Of the 13-inch pipes the damage amounted to 10½ per cent. In the case of the 12-inch pipes, which were exactly of the same weight as that adopted for Port Elizabeth, there was a loss of 7½ per cent. Those figures appeared to indicate that in designing waterworks abroad not only must the thickness of the pipe required for the ultimate work it had to do be considered, but the voyage the pipe had to make across the sea must also be borne in mind. A very little difference in the thickness in the case of the Calcutta pipes at all events seemed to have preserved them. In the 24-inch pipes the loss was only 3 per cent. All the pipes were turned and bored. There were nearly 13 miles of 42-inch turned and bored pipe. It was a very bold thing to lay a main of that character in alluvial soil with turned and bored pipes; and, from what he had learned from the workmen in charge of the works since they had been finished, he could not say that the main had given satisfaction. A great deal of trouble had been experienced, and the information he had obtained would lead him never to think of laying so long a length of large pipes with only turned and bored joints. All throughout Calcutta the distribution pipes, which amounted to about 10,000 tons, had turned and bored joints and worked under considerable pressure. He thought that 60 feet would be the ordinary pressure; but the pipes and joints had all

Mr. Lewis. been tested to a great deal more, and had never given any trouble. They were not jointed with lead but simply turned and bored, and they stood remarkably well. The works were opened in 1871, and had given great satisfaction. The only trouble had been with the 42-inch main. It had been found necessary to adopt lead joints at intervals in this main, and all the repairs had been made with lead joints.

Mr. Higgin. Mr. GEORGE HIGGIN asked Mr. Leslie why 3 feet 3 inches of broken stones should have been used in the bottom of the filter-bed. The only useful substance as a filtering material was fine sand. It had been always the custom to put in several strata of broken stones at the bottom, and graduated courses of fine material above; but some experiments that he had recently made led him to believe that that was not at all necessary; it was quite sufficient to put gravel at the bottom, and sand immediately on the top of it. He had experimented with different kinds of material, and he had found that in no case did the sand run down or mix with the other substances, and he ultimately took out all the coarse material, and put in 4 feet of sand and 6 inches of coarse gravel, and the filter answered much better than before. If his theory was correct, nearly 4 feet might be done away with in the Edinburgh filter, and the same practical result obtained. The matter was important, because by the plan he proposed, the cost of filters might be considerably reduced.

Mr. C. Hawksley. Mr. CHARLES HAWKSLEY thought that the excessive breakage of pipes in transit to Port Elizabeth must have been due in great measure to the bad stowage on board ship. No doubt the addition of a small belt at the spigot end of the pipe would do much to prevent breakage from ordinary causes, but would not obviate the breakage due to the want of proper stowage. Mr. Gamble had recommended that the testing of the pipes should be performed after the coating had been applied in order to prevent them from becoming rusty; but Mr. C. Hawksley thought it would be a greater evil to test the pipes after coating, because the soundness of a pipe could not then be so easily determined. The rusting might be prevented by testing with oil instead of water, as was now being successfully done on a large scale. There was one singularity in the pipes at Port Elizabeth which he had never known in any others, viz., the drilling of the small hole shown in the section of the socket, to admit the escape of air when the joint was being run. Many thousands of miles of pipes had been successfully laid without any such provision being made, and he could not therefore think it was at all requisite. With reference to the difficulty of making the

double-beat valves tight, that difficulty was frequently caused by the body of the valve not being sufficiently stiffened to prevent change of form when subjected to varying pressures. In valves of that nature the slightest change in form of the body altered the relative positions of the valve-seats, or it might be that the valve-faces and their connecting spindle became slightly distorted. A change of form in any of those parts must necessarily result in leakage, and it was needful to make them of enormous strength in order to prevent such change. Mr. Addy recommended that the distributary pipes should be connected together as much as possible, so that the water might have free circulation in all directions. In practice that was frequently found to be very objectionable, inasmuch as a district could not be shut off without closing in some cases as many as twelve or thirteen valves; and it was generally found preferable to have the pipes arranged, so that each small district was under the command of one valve. That would necessarily result in having a number of dead ends, but if they were regularly flushed out no inconvenience was found to arise. It had not been stated in either of the Papers what the result of the works described had been, viz., the quantity of water consumed in the different towns. He believed that in the case of Edinburgh, where, however, the distribution was not under the control of the Author of the Paper, a vigorous examination had been made for some years past of the various districts into which the city was divided, and the result had been that the waste in each district had been very much reduced; but notwithstanding this temporary reduction the total consumption in the city had year after year remained at or about the same large amount of 32 gallons per head per day. Mr. C. Hawksley.

Mr. G. BUCHANAN had recently returned from South Africa, and as he hoped on some future occasion to lay before the Institution an account of the Kimberley Water Works, he would now only say a few words respecting them. These works were interesting, not so much from their novelty, as from the exceptional difficulties—of transport, labour, and materials—in carrying on works of that kind 500 miles from the sea. One feature in their construction was the use of 14-inch wrought-iron pipes for 17 miles of main, rising 500 feet. Those pipes had been laid with perfect success, and out of six thousand joints only three were really bad. The principal reason for adopting wrought iron was the great cost of carriage up the country, which was £20 a ton. Although wrought iron cost £20 a ton and cast iron £6 a ton, there was a saving of £50,000 to the company by the use of Mr. Buchanan.

Mr. Buchanan. the former instead of the latter. The ends were protected. At first he had disks of wood 2 inches thick hammered into the end of each pipe, and fastened by screws through the sides of the pipe, but that was not effectual; because firewood was so scarce that out of a large proportion of the pipes only two disks reached Kimberley, the rest being used on the way for fuel. The remainder of the pipes were protected by two iron straps 1 inch by $\frac{1}{4}$ inch crossing one another and riveted to the sides of the pipes. They all arrived in safety. The percentage of waste from breakage was practically nothing. The thickness of the iron in the pipes was $\frac{1}{4}$ inch, and they were perfectly cylindrical, the joints being made with a wrought-iron collar, and each end of the collar run with lead and calked. A length of 20 miles of cast-iron pipes had been laid in the town.

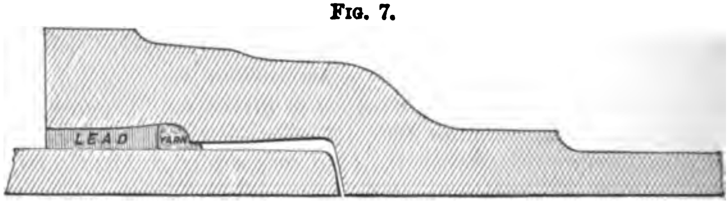
Mr. Homersham. Mr. S. C. Homersham said it had been suggested that beads should be cast on at the ends of pipes to prevent breakage. He never put beads upon the ends of pipes as he considered it was disadvantageous to do so. If there was a broken end, and no bead on, it could be cut off and used in the socket without trouble. He had made large pipes, some as much as 42 inches in diameter and only $\frac{3}{4}$ inch thick, cast in Middlesbrough, shipped in the Thames, taken half across the world, and then carted 30 miles into the country, and so successfully were they conveyed that the few additional pipes sent for use in case of breakage were not required. On the end of every socket of these pipes a permanent wrought-iron hoop was firmly shrunk, and in the length of the body of the pipe, 9 feet, two similar half-round wrought-iron hoops were shrunk. On the spigot end a temporary rectangular hoop was shrunk, that was afterwards taken off when the pipes got to their destination. That sufficiently protected the pipes, and there had been no breakage. The joints were all made of cold drawn lead, well calked, and stood well. In case of smaller cast-iron pipes, over 6 or 8 inches diameter, he had shrunk on the spigot end a small temporary rectangular wrought-iron hoop, which when it was cut off it could generally be sold for about the same price as it cost. The absence of beads enabled the pipe-layers, in case of accident to the spigot end, to cut a few inches off the pipe, which could then be used. That could not be so well done where a bead was cast on. He had always adopted the practice of making the inner portion of the joints in solid lead, and never put in yarn, as that was found to rot and injure the quality of the water. With such lead joints he had hardly ever had a leak, and the pipes had rarely been broken. He

had annually sent many thousands of tons of pipes half round the world during the last twenty years, and had not had more than two or three per cent. broken. These had mostly been broken in the spigot end, which were cut off and the pipes then used. Mr. Homersham.

Mr. H. J. Marten was inclined to agree with Mr. Latham with reference to turned and bored joints. In 1875 he had occasion to examine a main laid with turned and bored joints in connection with the Dundee water-supply. The main was 14 miles in length and 27 inches in diameter. On the main being charged considerable difficulty arose owing to the large number of split sockets, the question of responsibility in connection with which led to litigation. The difficulty was to a certain extent eventually overcome by cutting out several of the bored and turned joints and substituting ordinary calked lead joints for them, leaving sufficient play in the socket between the spigot end of one pipe and the shoulder of the next to allow of expansion without their touching. In this way the effect of expansion was confined to comparatively short lengths of pipe, and the bored and turned joints intervening between each of the lead joints were preserved from splitting pressure. The pressure upon this main was in some parts very great (in one it was upwards of 200 lbs. per square inch); the difference between the summer and winter temperature of the water passing through it was also considerable, and he remembered a singular circumstance in connection with the lead expansion joints, due, in his opinion, to the combined influence of the pressure and expansion. When the spigot end of a lead-jointed pipe was drawn out of the socket by the contraction of the pipe, it partially pulled the lead joint out of the socket with it, causing the lead, in some cases, to protrude beyond the lip of the socket about $\frac{1}{16}$ inch; but when with expansion the spigot end receded into the socket, it failed to take back the protruding portion of the lead with it. When, therefore, the next contraction took place a little more of the lead joint came out, so that step by step the lead joint was gradually withdrawn from the socket. To prevent this movement of the lead he had found it advisable, when provision had to be made for heavy pressures, to have the sockets, though parallel for about half the depth of the lead joint, slightly coned at the back of the "lead pouch." This arrangement, by giving a greater thickness to the lead there, effectually prevented its being brought out of the socket on the pipe contracting in length. About half-way between its lip and shoulder the socket was contracted so as to allow of a play of about $\frac{1}{8}$ inch in the smaller pipes, and of $\frac{3}{16}$ inch in the Mr. Marten.

Mr. Marten. larger ones between the outside of the spigot and the inside of the contracted part of the socket. This contraction of the socket had the effect of aiding to hold the pipe in its proper place. Beyond the contracted portion of the socket above described it was again coned out, so that in the event of the pipe having to be slewed there should be sufficient play left for the purpose to prevent the spigot end of the pipe being nipped by coming into contact with the sides of the socket. It was also his practice to have the shoulder of the socket and the spigot end of the pipe bevelled, an arrangement which gave a little more play for slewing than was the case with the ordinary square shoulder and spigot end (Fig. 1). A slight stopping of yarn was inserted at the back of the "lead pouch," and the joints were then run with lead and calked in the usual way. He had found joints made in the manner described

Fig. 7.



Pipe Joint.
Scale ⅛.

stand remarkably well under heavy pressure, and in ground liable to subsidence from mining operations. In one case a 22-inch main, jointed as above described, had, owing to mining operations, subsided something like 13 feet in a length of 100 to 150 yards without leakage. The pipes were subsequently raised to their original level, and the joints remained tight during the operation without the necessity of setting them up again, and with the water at its ordinary pressure passing through them during the whole time they were being lifted. He did not consider the double angle adopted for the Port Elizabeth socket to be an advantage, nor had he ever found any occasion for air-vents such as those shown in the drawing of that socket, and he considered them to be altogether unnecessary.

It had been stated in Mr. Gamble's Paper that "The sluice-valves are of the usual pattern." The usual patterns of the present day were in wonderful advance of those of thirty or forty years since. The great improvement originated with the introduction of "the double-faced sluice-cock." This sluice-cock, which

had now superseded every other description, was the creation of Mr. James Nasmyth's inventive genius. Mr. Marten well remembered the first inception of this useful invention, as he happened—being at that time a pupil of the late Mr. Thomas Wicksteed, M. Inst. C.E.—to have been present when Mr. Wicksteed explained to Mr. Nasmyth the want he experienced of a sluice-cock for waterworks purposes, that should shut and remain perfectly tight against a pressure coming from either side. Mr. Marten had a lively recollection of the instantaneous rapidity with which Mr. Nasmyth not only grasped, but provided for, the requirement, so that almost by the time Mr. Wicksteed had completed the statement of his want, Mr. Nasmyth had drawn upon the back of an old letter a rough sketch of the first double-faced sluice-cock, and in less than an hour had converted this rough sketch into a full-sized working drawing, in the preparation of which it fell to Mr. Marten's lot to have the honour to assist. In his autobiography Mr. Nasmyth referred to the conversation with Mr. Wicksteed, and introduced a print of the drawing made upon the occasion. The invention had been of the greatest use to the waterworks' Engineer, especially in connection with the constant-supply system, in which it frequently happened that the pressure was sometimes against one face of the sluice-cock, and sometimes against the other. Mr. Marten.

He was much interested in the complete records which Mr. Leslie had submitted of the gaugings of several springs; they appeared to be most remarkable for the regularity of their flow. Three sets of them varied to a very slight extent during the course of the year, and in the case of the fourth the winter appeared to be only about three times the summer flow. He observed that the rainfall at Glencorse, 700 feet above Ordnance Datum, was much greater than at Moorfoot, which was 900 feet above Datum. In general, other circumstances being similar, the rainfall rather increased than diminished up to an elevation of 2,000 feet above mean sea-level. Probably, in the cases named in the Paper, there was some peculiar differential configuration of the high ground surrounding the respective rain-gauge stations which might account for the deviation from the general rule upon which he had remarked; and if so he should feel obliged by Mr. Leslie explaining the circumstances of each case.

With reference to the question of laying mains for the supply of towns on the constant system, with or without dead ends, he ought to mention that soon after the introduction of the constant-supply system he came to the conclusion that the old system of laying pipes

Mr. Marten. with dead ends was not the most advantageous; and for more than twenty years he had invariably adopted the plan, so far as possible, of connecting all the dead ends of the pipes so that the tendency of all the water supplied to a town would be towards the point of greatest consumption. He had not in practice found any difficulty arise such as that referred to by Mr. Charles Hawksley, namely, the having to close numerous valves in a district in order to isolate any particular street, because in the system as carried out by Mr. Marten, he had invariably placed a double-faced screw-valve at the end of each street, and in long streets occasionally an additional one in the middle; and in this way any street, or portion of a street, might as readily be isolated as under the dead-end system. In several cases he had had to alter the system of dead to one of connected ends, and he had always found a great advantage resulting from the change, especially to consumers drawing their supplies from near what were formerly dead ends.

He agreed with Mr. Rawlinson as to the great cost, £12 per thousand gallons, of the reservoir at Port Elizabeth. Probably this would, to some extent, be explained by the fact of the price of labour and the cost of materials being largely in excess of those at the same period in this country.

Sir John Coode. Sir JOHN COODE said he knew something as to the cost and character of labour usually available at Port Elizabeth. Up to a recent date, the Kafirs who landed material there were paid 8*s*. or 9*s*. or 10*s*. a day, and that rate of pay for labour alone would go far to account for the heavy cost of the reservoir. The rule of the natives appeared to be, "eight hours work, eight hours play, eight hours sleep, and 8*s*. a day," as in the Australian colonies. The expense of conveyance, too, was very great, and would help to explain the increased cost per 1,000 gallons capacity of the reservoir at Port Elizabeth as compared with the cost of reservoirs in England.

Mr. Atkinson. Mr. W. ATKINSON observed that the cubic contents of a reservoir increased as the square of the diameter, and the retaining wall (which was a large element in the cost) increased only directly as the diameter, and it was not therefore fair to compare a reservoir containing many million gallons with one containing a smaller amount. With regard to filtration through limestone rocks, Mr. Rawlinson had confined himself to mountain limestone, probably because in this country that was an expression for limestone generally. But all valleys of denudation were assumed to arise from some break in the rock, which had led the water to take that particular direction, and therefore in dealing with a valley of

denudation it should be assumed that there were fissures and cracks in it. But independently of that, in all countries where there was limestone, whether mountain or cretaceous, there were not only fissures, but long water-courses. With regard to the relief-valve, it had been said that it was desirable to make it heavy in order that it might not change its form; but the moment it was made heavy the object for which it was made, to act rapidly, was destroyed. The weight on the relief valve was done away with, and the spiral spring adopted instead. The spiral spring was inefficient, because directly it was compressed by the opening of the valve, a greater pressure was put upon it, and therefore the ingenious device described in the Paper had been adopted. But valuable as the relief valve was, the Author stated that it adhered, and it seemed that water engineers had still to invent some mode by which they could rely upon a valve acting readily, and always being in a state to act. Mr. Atkinson.

Mr. Leslie, in reply, said he agreed with Mr. Rawlinson, that the proper position of the valves on the outlet pipes of reservoirs was inside. The reservoir to which he alluded, was the Glencorse reservoir, at Edinburgh, designed by Mr. Telford, which had stood for sixty years. In that case the valve was not outside the slope of the reservoir but in the centre of the bank. If it had been outside, there would have been greater danger, because, had any leak occurred, it would have affected the earthwork of the outer slope. With regard to the rate of filtration, which was said to be in Edinburgh double the rate in London, it should be remembered that the London water was taken directly from the river, and had not the advantage of subsidence in large reservoirs like the water in Edinburgh, where it was found to be sufficiently filtered even at the greater rate. Mr. Leslie.

Mr. Rawlinson observed that the London water companies had all made subsidence reservoirs. Mr. Rawlinson.

Mr. Leslie imagined they would not hold anything like six months' supply. As for the length of by-washes, the value he had given, 1 foot for every 44 acres, did not differ materially from the proportion mentioned by Mr. Rawlinson, but he thought it depended a great deal upon the relative height of the crest to the top of the bank. The cost of the reservoir at Alnwick Hill was under that mentioned by Mr. Rawlinson, £5,000 per million gallons, the amount being £4,900, which he thought was pretty cheap. It was Edgelaw reservoir, and not Gladhouse, where the incident occurred with regard to the slip in the face of the bank. He thought it was a good plan when working with material of Mr. Leslie.

Mr. Leslie. that kind, to incorporate with it as much stone as possible, so as to prevent slipping. To prevent cracks in the puddle-wall from the effect of the sun, it was a matter of great importance to deposit a sufficient amount of earth, or some other material not affected by the sun, on the top of the wall. It was scarcely fair to mention with reference to the question of pipes, that there was a difference of 33° of temperature at 2 feet 6 inches below the ground, because large mains were rarely able to be put in such a shallow track, and the fact of water being in the pipes would tend to keep them at a much more equable temperature. He thought it was a mistake to have compound joints on the pipes, first to turn and bore them, and then to lead them, because by that means an excessive strain was put upon them. The reason of the failure of the Dundee pipes was, he thought, that they were too thin, both in the body and in the faucets, and the excessive strain put upon them was too much for the metal. They were also laid, in some places, in treacherous ground of a mossy character, and they should have been supported by piles; but that precaution had not been adopted. He thought the only reason for selecting turned and bored pipes at all was their cheapness, and so long as they were in ground which was undisturbed, they did tolerably well. They had laid within the last five or six years about 20 miles of turned and bored pipes from 18 to 24 inches in diameter, and the percentage of breakages had been very small. The general rule in such cases was to have 10 per cent. of the pipes with plain joints, which had a useful effect in the case of expansion and contraction. As to the 3 feet 3 inches depth of material put into the filter-beds it seemed a great deal, but that was the maximum amount, and it was necessary to have a sufficient quantity to cover the outlet-pipe which was 22 inches internal diameter: to this had to be added the size of the faucets and the thickness of the pipes, and with items of that sort there was a total depth from the floor of concrete to the top of the faucet of 30 inches, so that there was only 9 inches to come and go upon, for spreading over the floor and covering the top of the pipe. Of course, anything that could lessen the depth of the filter-walls, would be of great advantage, as that was a most expensive part of the operation. As to the laying of distribution pipes, it had been found advisable to adopt the principle of dead ends rather than to have a constant circulation which tended to cross currents. In every pipe there must be some sediment, and as it got stirred up the water became turbid, but if the water was always kept flowing in the same direction that was not likely

to happen. He agreed with Mr. Hawksley that the rate of consumption in Edinburgh was a great deal more than was necessary, varying from 32 to 40 gallons per head. Not long ago he had sent in a report to the Edinburgh Water Trustees, directing attention to the fact, and showing that during the night from Alnwick Hill reservoir, at a minimum flow, water was running into Edinburgh at the rate of 5,000,000 gallons per day, and as all the houses were fitted with cisterns which were always kept full, it seemed that that amount of water was being wasted. As, however, it would cost some money to provide a proper inspection, meters and regulations, and as there was double the quantity of water required, the Trustees had instructed him to let the matter alone, because the waste was doing no harm. He had been asked why the rainfall at Moorfoot was so much less than at Glencorse. It was expected on the first visit to the ground that it would have been otherwise; but on looking at the lie of the land the matter could be explained. With a south-westerly wind, the prevailing one that brought rain, the Glencorse was the first range of hills to catch the water-bearing clouds. In the case of the Moorfoot Hills there was a large range lying between the district of supply and the place where the rain came from, and it was found that upon the south side of the range the rainfall was much greater, showing that the clouds must have expended themselves in a great measure before arriving at the drainage area of Gladhouse. Mr. Leslie.

Mr. J. Wolfe Barry said, as he had been consulted by the Municipality of Port Elizabeth with reference to the English contracts for their waterworks, he might be permitted to say a few words. His functions had been almost entirely ministerial, and to Mr. Gamble was due the credit for the works that had been so carefully designed. No doubt the breakages of pipes had been abnormally great. The only explanation to be given was that they were very badly stowed. Under the contract the responsibility was left with the contractor. His attention had been drawn over and over again to the breakages, and he was mulcted to an amount of about 30 per cent. of breakages under the first contract. Under the second contract, Mr. Gamble, to avoid the delays and other inconveniences of the breakages, insisted on the precaution being taken of putting wrought-iron bands round the ends of the pipes, and on extra care being taken as to the stowage, and the result was the breakages went down to 4 per cent., which was pretty clear evidence that the previous breakages had been due to carelessness. The pipes had been tested both in England and at the Cape, and Mr. Barry.

Mr. Barry. the result was satisfactory. The pipes were generally found to be very good when tested a second time. Owing to the great cost of carriage, it was desirable that no imperfect pipes should be carted up the country. The joint to which reference had been made was remarkable for its shortness, and for the economy of lead effected in it. The lead used for the joints at Port Elizabeth varied in the large pipes from 7½ lbs. to 10 lbs., as against 15 lbs. or 17 lbs. for similar joints made in the ordinary way. The dovetail form of the casting was also found very successful, and the yarn at the end allowed some amount of swagging of the pipes in passing round the curves. He could not personally say anything as to the advisability of the small drilled hole. It did not cost much, and Mr. Gamble thought it enabled the joint to be made more efficiently. No allusion had been made in the discussion to the fact that the lead joints in the town had been made with brass couplings, and no solder had been used. The joints were made with very great ease, they did not require any skilled labour, and had been a great success. The municipality had decided to supply the fittings themselves, and to be responsible for the fixing. The result had been simplicity and uniformity of work. Some remarks with reference to the cost of the service-reservoir showed the danger of generalisation on such points. Sir John Coode had pointed out the real reason of the cost, and it was also pretty well explained in the Paper by the statement of the actual cost of the concrete. The concrete had to be made of broken stone. Cement was very expensive, and the sand had to be brought from a distance of 3½ miles, the result being that the price of the concrete was £2 5*s.* per cubic yard, which accounted for the cost of the reservoir. He wished to call attention to the serious effects now arising in South Africa from the denudation of the country by the felling of timber. The question was one of great importance, as the water-supply of many towns was being endangered while floods were being increased. He had reason to believe that the Government had taken the matter up, and would stop or control the disforesting that was wastefully taking place. The waterworks at Port Elizabeth had been carried out very creditably by all concerned, and by none more than by the late Mr. J. H. Wicksteed, whose untimely death he greatly deplored. The scale and efficiency of the works showed the public spirit of the municipality which had spent £130,000 to provide an efficient water-supply, not only for the present inhabitants but for posterity.

Mr. Addy. Mr. JOHN ADDY said the cost of the Peterborough reservoir

Mr. Addy. had been considerably enhanced by the fact that the bricks had to be brought from a distance of 20 miles, and the stone and sand for concrete from a distance of 3 or 4 miles, all being dragged up hill 120 or 140 feet above the road-level across fields. With regard to the question of turned and bored pipes, there was a condition that there should be 10 per cent. of lead joints, and that turned and bored pipes only should be used in straight sections. As the land was level they answered well, and there had been no abnormal leakage from them. The water, coming as it did from a well, varied but little in temperature, and that would tend to prevent the pipes either contracting or expanding. There was a saving of 1*s.* 4*d.* a yard, which in 25,000 yards amounted to £1,500, so that he thought the use to so large an extent of turned and bored pipes was justifiable. It had been attempted as far as practicable to have no dead ends, but it was impossible for any town to have all connected ends; wherever it could be done there were no dead ends.

Mr. Gamble. Mr. JOHN G. GAMBLE observed, through the Secretary, that the heavy cost of the reservoir, as Sir John Coode and Mr. Barry had pointed out, was partly owing to the high price of labour and cement; but a great portion was due to the bad quality of the rock. Generally around Port Elizabeth the rock was hard quartzite, and two trial pits sunk at the site showed hard quartzite; but in the process of excavation the rock was found to be so fissured that a very large extra quantity had to be removed.

Correspondence.

Mr. Bruce. Mr. A. F. BRUCE observed that the amount of water, stated by Mr. Gamble to have been delivered by the main pipe at Port Elizabeth, appeared to have been exceedingly small, on the supposition that it ran full bore. As calculated by D'Arcy's formula, a 12-inch pipe laid at a gradient of 1 in 394·3, should deliver 1,159,000 gallons in twenty-four hours, and a 9½-inch pipe at 1 in 90·8 a somewhat larger quantity. Pipes, when first laid, generally discharged considerably more than the calculated amount; he had known them to do so on works under his charge to the extent of 50 or 60 per cent. It was, of course, difficult to attempt to criticise works without a full knowledge of all the circumstances of the case; but it seemed a mistake to expose pipes to the danger of fracture by falling stones or otherwise, and the variations of temperature, by bracketing them on the face of the cliffs, if any

Mr. Bruce. other route could have been adopted where they could have been laid underground. Frequent stop-valves were decidedly dangerous under heavy pressures, as they exposed the pipes to the risk of "shock," if they were carelessly used, and automatic air- and relief-valves seldom worked well. Mr. Gamble did not mention if scour-valves were placed in the various hollows, if so, pipe-scrapers were surely unnecessary.

With regard to the Peterborough waterworks, he thought the service reservoir might have been constructed more economically, and quite as efficiently, without either the brick lining or the puddle, as concrete could easily be made perfectly watertight, and with an excellent face. But on the whole it was a cheap scheme.

r. Matthews. Mr. W. Matthews remarked that the waterworks of Peterborough had been of a very costly character, considering the population to be supplied. Mr. Addy accepted the principle that distance from the source was the chief cause of this; and it seemed strange that stronger endeavours were not made to obtain a supply nearer at hand. A precisely similar geological formation to that selected existed at Chesterton, 5 miles away, and considerable springs were found there. The pumping-station would have been better situated nearer to the public road and the reservoir. The first site of boring was subject to flooding, and at the second site the water got into the foundation-pits of the engine. A cost of £4·127 per head was very heavy. Of two hundred and thirty-five towns in this country, tabulated by Mr. G. W. Usill, Assoc. M. Inst. C.E.,[1] in only seventeen did the cost per head for water-supply exceed £4. Of these towns, thirteen were supplied on the gravitation principle, involving light working expenses. At Peterborough the expenses were heavy, as the reverse was the case. Doubling the present population of the town, and adding all towns and villages, including Whittlesea, within a radius of 5 miles, and 1 mile on each side of the main, the total population would come up to 65,500, which at 20 gallons per head, would require 1,300,000 gallons of water per diem. This was fairly the work of one engine for twenty-four hours; but an 18-inch main, with the present fall, would discharge, according to accepted formulas, about 2,800,000 gallons; and it was evidently larger than necessary. A service reservoir of 1,000,000 gallons capacity would, if the main were well designed, be almost useless. The present consumption was about 300,000 gallons, equal to 20 gallons

[1] Statistics of the water-supply of the principal cities and towns in Great Britain and Ireland, compiled from official returns, 1881.

Mr. Matthews per head; and the pressure with this draught was practically unaffected. A 12-inch main would have been ample, and the benefit of a duplicate might have been experienced in the future. The water now remained far too long in contact with the pipes, and necessitated constant flushing at much expense. It was to be regretted that no mention had been made of the partial failure of the reservoir, as it was an example of puddle-clad work, which was open to much criticism. In the first place two cross walls 4 feet high were put in to keep the floor down and the walls up; and a recent survey of the structure showed that at a height of 12 feet above the floor, and at about the original level of the ground, the side walls had come over considerably, and were much bulged, the arches being distorted, and torn away from the wall below the haunches. The end walls had been kept up by the internal wing-walls, and had not been distorted. He had calculated that the walls would come over bodily were they not supported at the top by the roof-arches, and the bulging below was the result. The floor, which was of concrete, varying from 9 inches thick at the edges, to 6 inches thick in the centre, had risen to a considerable extent, and was cracked all over; this was no doubt due to the weight of the surrounding walls upon the puddle skin, forcing it up inside. The repairs had already cost £500. The stand-pipe arrangement was bad, as it allowed of a varying head of water upon the pumps and machinery. Its use had been discontinued, as the extra pressure was not required. The reservoir leakage was inappreciable; that on the 18-inch main was 8,000 gallons in twenty-four hours. The engines were too heavy for their work, even to lift double the available head; for if they had been for a head of 108 feet, the engines would have been exactly suitable. This provision gave no scope for increased demand in quantity, but for pressure alone; and the policy was questionable of erecting engines which for many years at least could not give better results than 1 HP. for 3·59 lbs. of coal, or 45,000,000 of duty when on a trial. It was contemplated to substitute cylinders of 22 inches diameter at an early date. It had been impossible to put this machinery upon its contract trial for want of the necessary head of water. The duty should have been 80,000,000. The water made five right angles in passing from the suction main into the supply main, and the areas of water-way were so small in the buckets that the velocity of the water was 3·5 feet per second, in the suction-valve it was 1·8 foot, and in both cases, the lift of the valves, 2¼ inches, was at least double what it should have been. The suction-valves originally had an

Mr. Matthews.

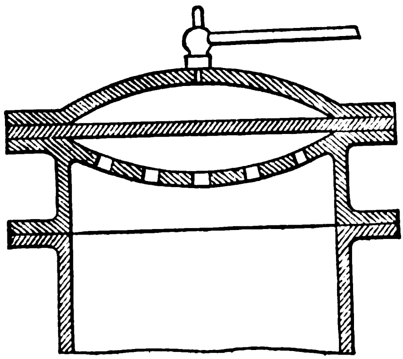
PETERBOROUGH CORPORATION WATERWORKS. Trial of Engine A, May 8th, 1883.

Cylinder, 2 feet 8 inches; Piston Rod, 4¼ inches in Diameter; Length of Stroke, 6 feet.	No. of Observations. 1st Set	2nd Set.	Total.	9 A.M. to 12 mid.	12 mid. to 3 P.M.	Whole Trial.
Hours pumping	..	..	..	3	3	6
Revolutions of engine	12	12	24	2,702	2,705	5,407
„ „ per minute	..	..	..	15·01	15·03	15·02
Boiler pressure, by gauges (2)	12	12	24	19·29 lbs.	19·79 lbs.	19·54 lbs.
Initial „ by diagram	24	24	48	15·84 „	16·52 „	16·18 „
Vacuum „	24	24	48	26·35 ins.	26·55 ins.	26·49 ins.
Barometer	2	2	4	29·55 „	29·53 „	29·54 „
Average pressure in cylinder	24	24	48	13·587 lbs.	13·599 lbs.	13·592 lbs.
Steam cut off at	..	..	..	..	..	17·5 per cent.
Indicated HP., cylinder 32 × 72 ins., piston rod 4¼ ins.	24	24	48	58·896 HP.	59·171 HP.	59·033 IHP.
Coal consumed, South Welsh, 756 lbs.; Derbyshire, 516 lbs.	..	..	..	..	..	1,272 lbs.
Coal consumed per indicated HP. per hour	..	..	..	..	..	3·59 „
Temperature of boiler feed, in hot well	12	12	24	91°·0	91°·3	91°·15
„ of injection water from main	12	12	24	53°·65	52°·50	53°·02
Pressure on air-vessel gauge (71·62 feet above O. D.)	12	12	24	54·83 lbs.	54·91 lbs.	54·87 lbs.
Water pumped, by diagram, and measured in reservoir	12	12	24	151,315 galls.	151,479 galls.	302,794 galls.
Water pumped per revolution	..	..	..	..	..	56 galls.
Percentage of total capacity of pumps	..	..	..	..	..	91 per cent.
Height of lift, mean level in well 32·49 feet above O. D.	12	12	24	..	Suction	16·63 feet.
„ Suction valve 42·12 „ „	..	..	..	..	Force	149·87 „
„ Top of stand pipe 198·99 „ „	..	..	..	..	Total	166·50 „
Duty of pumps, in foot-pounds	..	..	..	250,865,138	253,303,183	504,152,010
„ „ „ per cwt. of coal consumed	..	..	..	..	..	44,379,500
HP. of pumps	..	..	..	42·06	42·64	42·44
Efficiency of engine	..	..	..	0·71	0·72	0·715
Temperature of engine room	2	2	4	62°	65°	63½°
„ of outer air	2	2	4	49°	51°	50°

Piston and rings examined and found tight. Pumps and valves tight and in good working order. Air-cock on suction valves slightly open during trial. Boiler No. 2, next to engine-room; been at work three weeks since it was cleaned, fittings all steam tight; pipes partly lagged. Fires cleaned out just before trial, and at end of trial were in slightly better condition. Coal—Powell Duffryn, at 20*s.* 9*d.*; and Pinxton at 14*s.* 1*d.* per ton delivered.

air-snift valve on the covers, drawing in air at each stroke of the pump; this was confined above the water by an india-rubber diaphragm with perforated guard (Fig. 2); upon the downward stroke this was compressed, and the thrash on the beats was enormous. He did not know what had been the anticipated Mr. Matthews.

Fig. 2.



Suction Valve-Chest.

action of this arrangement, as upon its removal a saving of 27 per cent. had been effected. The full pump was 62 gallons; the present discharge 56 gallons, and with the air-snift only 45 gallons per revolution of the engine. The intermediate casting had been removed, and the air-snift cock reversed, so as to discharge the air from the valve-chest.

Mr. Malcolm Paterson, referring to the passage of the Moorfoot water scheme through Parliament, and the 750,000 gallons per day demanded by and yielded to the riparian landowners, observed that this fact was directly opposed to a theory held by most of the promoters of Water Bills; that excepting the usual compensation works, the abstracters of water were neither legally nor equitably bound to pay for what they took and consumed, viz., the remaining two-thirds of the available rainfall, and that there was no precedent for the admission of such obligation. The question was of frequent occurrence, and had arisen in his own experience in opposing the Wakefield Water Bill of 1880, where the sole proprietor of the gathering ground demanded the insertion of a clause entitling him to such payment for the water taken, if any, as might be decided by arbitration. This case was compromised, but it would be interesting to know if such a water-right had ever Mr. Paterson.

Mr. Paterson. been recognised by judicial decision, or by that of a parliamentary committee. Passing to the subjects of the pipe conduits and distributing mains, he had noted no reference, in any of the Papers, to the only scientific method of testing such conduits, namely, by hydraulic pressure applied while the trenches were open, so that an inspector could, while more than the working pressure was on, ring every pipe with his hammer, and pass his finger round every joint, and so lay his hand on every flaw, have it remedied, and the whole re-tested before being covered and hid from sight. This had been the practice of a few engineers, and had been carried out by himself in laying 25,000 yards of mains at Ossett, in the West Riding. The time would come when no engineer would bury his work untested, when so economical, so complete, and so simple a test could be applied. Even where a pipe was perfectly sound when rolled into the trench, the most skilful caulker could not always tell when he had broken a weak socket, or whether a spigot had not split after passing the separate test. Every water engineer knew the anxiety and expense of leaking conduits and mains, and the loss of water from this source was very great. The present practice appeared to him, with all deference to high authorities, the reverse of scientific. Science was prediction, and there was no prediction in the absence of a test of work of this nature. He could not agree with Mr. Gamble's remarks as to the shape and the depth of the sockets. The wide front and narrow back afforded no resistance to "drawing" or to "blowing," under enormous pressure, but facilitated them, which was a great drawback, especially in a coal country, or in any case of yielding foundation. To prevent this, he had used a space at the back, slightly wider than the front, with success. Again, shallow sockets with wide mouths make it easy to "swag" or twist the pipes from a right line, and not difficult, as stated by Mr. Gamble.

Mr. Willcocks. Mr. G. W. Willcocks remarked that at Pieter Maritzburg, Natal, it was found that not 5 per cent. of 12-inch main pipes had been cracked after being sent from Glasgow to Durban, and thence 60 miles, partly by railway and partly by ox-wagons. Of pipes 6 inches and 4 inches in diameter not 1 per cent. had been broken. At Kimberley, after a journey inland of more than 500 miles, partly by railway and partly by ox-wagons, cast-iron pipes, 6 inches and 3 inches in diameter, were in good condition, not 2 per cent. having been cracked. The 12-inch pipes at Maritzburg were 9 feet long, and weighed 6 cwt. 1 qr. The 6-inch and 4-inch pipes at Maritzburg and Kimberley were 9 feet long,

and weighed 2 cwt. 1 qr. 26 lbs. and 1 cwt. 1 qr. 22 lbs. respectively. The 3-inch pipes at Kimberley were 6 feet long. A total of 6,000 lineal yards of 6-inch pipe was ordered for Kimberley, and it was found, after careful measurement with a chain, that 5,997 lineal yards of pipe had been laid in the ground. The cast-iron pipes, both for Maritzburg and Kimberley, were made by Messrs. Edington and Sons, of Glasgow. It would be noticed that most of the large pipes at Port Elizabeth were 12 feet long. This was, in the opinion of some manufacturers, too great a length for export pipes under 15 inches diameter, but not for pipes 15 inches in diameter and upwards. Then, again, the large pipes at Port Elizabeth were made in the North of England; and there could be no doubt that pipes manufactured at Glasgow were stronger, partly on account of the different irons used, but principally on account of the method of mixing them, and the proportions used of different brands. Although rough weather might have caused the breakage of many of the pipes for Port Elizabeth, yet it seemed that the iron must have been of a somewhat brittle character. Mr. Willcocks.

With regard to turned and bored pipes, he had laid upwards of 30 miles, in semi-tropical weather, both at Maritzburg and at Kimberley. When the water was admitted into the pipes, considerable contraction took place; but leakages only occurred at the weakest joints. Every fifth joint was composed of an ordinary socket and spigot, and leaded in the usual manner. Where skilled labour was scarce, it was certainly advisable to use turned and bored pipes; but it would be useless in such a case to run all the joints with lead, as nothing would be gained by this process. Mr. Rawlinson criticised the prices at Port Elizabeth, but it was impossible for an engineer only accustomed to home work to form an opinion of the cost of foreign engineering undertakings. The average price of rubble masonry in cement in Natal was £3 per cubic yard. The same in Kimberley, 500 miles inland, was from £11 to £13 10*s.* The price of a barrel of cement in Natal was about 25*s.*, and in Kimberley £6. In the Thames the cost was only 7*s.* The Kafirs worked from sunrise to sunset, and in Natal received 2*s.* 6*d.*, and in Kimberley 5*s.* (or even more) per day.

As regarded the movement of water in pipes, when the water circulated, not only were "dead ends" done away with, thus enabling the pipes to be better cleansed, but in case of fire, should two or three hydrants be attached to a small pipe, the circulation brought various pressures to bear, and caused a better flow of water.

29 May, 1883.

JAMES BRUNLEES, F.R.S.E., President,
in the Chair.

The following Associate Members have been transferred to the class of

Members.

EMERSON BAINBRIDGE.
JAMES BARRON.
WILLIAM BRENTNALL.
JOHN BRUCE CRAWFURD.
JAMES FRASER.
ALFRED JOSEPH GOLDSMITH.
JOHN PURSER GRIFFITH.
JOHN MACKENZIE.
JAMES MCRITCHIE.
JOSEPH PRIME MAXWELL.
CARL AUGUST BERNHARD NYSTRÖMER.
Hon. RICHARD CLERE PARSONS.
Baron EMILE THEODORE QUINETTE DE ROCHEMONT.
WALTER HAMPDEN THELWALL.

The following Candidates have been admitted as

Students.

ALFRED CHAMPNEY BOTHAMS.
EDWARD WINGFIELD BOWLES.
JOHN BROUNLIE.
COURTENAY THORNTON CLIFTON.
CHARLES SAMUEL CRAVEN.
WILLIAM JAMES HEDGMAN.
HORACE LONGUET HIGGINS.
DOUGLAS EARLE MARSH.
ASHBY FREDERICK OSBORN.
JAMES SAXBY, Jun.
FRANCIS WAKEFIELD SPENCER.
SIDNEY BOYD STEVENSON.
PERCY KENDALL STOTHERT.
CHARLES ARTHUR STRUTT.
WILLIAM ALEXANDER LISLE TAYLOR.
JOHN PEVENSEY TUPPEN.

The following Candidates were balloted for and duly elected as

Members.

WILLIAM BENNETT.
CARTER DRAPER, A.B.
WILLIAM BARNS KINSEY.
CARLOS ALBERTO MORSING.
WILLIAM PARKER.
FRANKLIN COGSWELL PRINDLE.
DAVID SIMMS.
PETER WHYTE.

Associate Members.

Charles Aburrow.
John Francis Albright.
Andrew Fawcett Ayre.
George Reginald Bayliss.
Harry Macdonald Becher.
William Henry Bird, Stud. Inst. C.E.
Alfred Barton Brady.
Alan Brebner, B.Sc., Stud. Inst. C.E.
Thomas Brook.
Henry Parsall Burt, Stud. Inst. C.E.
Randal James Callander.
William Richard Hopkins Chipperfield, Stud. Inst. C.E.
Robert Edden Commans.
Frederick George Cooke, Stud. Inst. C.E.
William Henry Robinson Crabtree, Stud. Inst. C.E.
Joseph Cresswell.
Walter Cradoc Davies, Stud. Inst. C.E.
Rowland Harry East.
William Henry Edinger, Stud. Inst. C.E.
George Hay Edwards.
Gerald Fitz-Gibbon, Stud. Inst. C.E.
Edward Colin Foote, Stud. Inst. C.E.
Henry Walter Ford.
Joseph Hague.
Rudolph Hering.
Luke Mullock Hill.
William Henry Holttum.
Samuel Earnshaw Howell.
Edward James Jackson.
Thomas Stephen Lacey, Stud. Inst. C.E.
Reginald Laurence, Stud. Inst. C.E.
Joseph Leslie.
George Lopes, B.A.
Arthur Robert Lungley.
Joseph Meilbek.
Charles Simpson Twigge Molecey.
Henry Parker.
William Charles Punchard, Stud. Inst. C.E.
Henry Reilly.
Robert Smith.
James Brown Stephen, Stud. Inst. C.E.
William Lumsden Strange, Stud. Inst. C.E.
Albert George Thompson.
Richard Watkins.
James William Wyatt, Stud. Inst. C.E.

Associate.

George Forbes, M.A., F.R.S.E.

The discussion upon the Papers on "The Waterworks of—I. Edinburgh; II. Port Elizabeth, S.A.; III. Peterborough," by Messrs. Leslie, Gamble, and Addy, respectively, was continued throughout the evening.

31 May, 1883.

The Session was concluded by a Conversazione, which was given by the President and Mrs. Brunlees at the South Kensington Museum by permission of the Lords of the Committee of the Council of Education.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 1911.*)

"Graphic Methods of Computing Stresses in Jointed Structures."

By Charles Ormsby Burge, M. Inst. C.E.

The employment of graphic methods in the solution of engineering problems has for some time attracted the attention of engineers, especially those who have been engaged on the design of structures to which this simple process is applicable. The more ready comprehension of magnitude by direct appeal to the eye, and the facility with which, in most cases, its solutions check themselves, as it were, attract to the graphic, a preference to the analytical processes, in the minds of most practical men. This is not surprising, and there is little doubt that the science of mechanics will gain largely in facility of comprehension, as that of statistics has already done, by the help of such methods.

Several works have been published in this country and abroad on graphic statics since the late Professor Clerk Maxwell drew attention to the subject; and it is not with the object of putting forth any new theory on the subject that the present Paper and diagrams have been prepared, but rather to represent in a simple form the application to practice of known theories.

Eleven examples are shown in Plates 8 and 9, and these have been selected rather as showing the practical operation of the process, than as good examples of design.

As regards the stresses in members of jointed structures, such as trussed roofs, cranes, lattice-girders, &c., the graphic method is founded on the well-known theory in mechanics, that if any number of forces meet in equilibrium, in a point, and if each be represented in direction and extent by a line, the several lines, in their proper direction and sequence, will form a polygon.

It is on this principle that the diagrams in Plates 8 and 9 have been drawn; and it will be observed that each polygon has been followed completely round, even when the sides have been already gone over in the computation of stresses previously ascertained. In each example there is shown the skeleton of a roof-truss or other frame, with one or more diagrams attached indicating the

polygons, and a series of letters showing the correspondence between the two. The joints of the frame are numbered, and the letters attached to the members, or to the forces or loads acting, are identical with those of the corresponding lines or stresses in the polygon. The groups of forces or stresses about each joint, in equilibrium, constitute separate polygons.

The diagrams are formed with sides parallel to the members or forces about each joint successively, and each line corresponds in its length, on any fixed scale, to the stress on the member of the frame, or to the force to which it is parallel. Tension, which is denoted by broken lines in the figures, and by broken hyphens in the notation, is known by the direction in which the lines of the polygon are drawn; those drawn (taking into consideration the side of the joint on which the member is) away from the joint under consideration indicating tensile, and the reverse, compressive stresses. The closing of the figure on completion of all the polygons shows the correctness of the computation. The lettering opposite the numbers of the joints distinguishes the polygons, and is written in order, following the loads and stresses in their directions around the polygon. The letters which are underlined show stresses discovered by the construction of the polygon in hand, the others indicating those given or previously ascertained. No more than two unknown forces can evidently be found by the closing of a polygon; hence, where there is a joint around which there are more than two forces to be ascertained, the problem is insoluble by the graphic method.

In Fig. 1, Plate 8, a simple roof truss of five members is shown; acted on in the first instance vertically only, by the forces of gravity, namely, the loading represented by *c d*, *e c*, and *g e*, and by the reactions *d a* and *a g*. Commencing with joint No. 1, the sides of the polygon *c d*, *d a*,[1] are drawn parallel and equal (on any fixed scale) to the forces *c d*, and *d a*; continuing on with *a b* parallel to the member *a b*, and, as the polygon must close at *c*, where it began, *c b* is drawn parallel to *c b*, determining the required stresses by scaling the closed sides *a b* and *b c* respectively. As *a b* has been drawn, in going round the polygon, away from the joint No. 1, it represents a tensile stress, *b e* for the contrary reason showing compression. The load *c d* and the reaction *d a*, as regards the joint No. 1, are obviously compressive.

[1] In constructing closed polygons for the solution of stresses graphically, it will be frequently found, as in this case, that one or more sides are superimposed upon another, wholly or in part.

Proceeding with joint No. 2 in the same manner, the polygon *e c*, *c b*, *b f*, *f e* is obtained, *e c* the load, and *c b*, which has been found by the preceding operation, being given.

In the figure for joint No. 3, which in this case is a triangle, *a b* and *b f* being known, the remaining line of the figure *a f* parallel to the member *a f*, should close in on *f* if the drawing has been correct.

Finally, the tracing of the polygon *f a*, *a g*, *g e*, *e f*, the sides of which are all either given or previously found, completes the computation.

In this example the effects of oblique forces in loading, such as those produced by wind, are computed in the same manner, and the algebraic sums of the lines *b c* and *b' c'*, *a b* and *a' b'*, &c., give the maximum stresses. In this case the oblique loading is shown from the left side only; but, of course, as this may come from the right instead, the greater of the stresses due to obliquity on either of two corresponding members in the diagram for oblique loading, must be assumed as that to be borne by each.

In roofs or similar structures, when the attachment to supports is on one side only, the reaction to oblique pressure is limited, theoretically, to that side, and in that case, in order to be strictly accurate, the diagram should be modified accordingly.

Fig. 2 shows a similar operation in the case of a roof-truss with more bracing.

Fig. 3 represents a form of strut often used between railway retaining-walls in cutting, treated first as without weight and acting as a strut only, and in the second diagram as carrying a load also, supported at joints Nos. 3 and 4, the triangular portions in this case being cantilevers loaded at those joints and fixed at 1, 2, 5 and 6. In the latter case the algebraic sums of the results of the two diagrams should be provided for.

In Fig. 4, the difference between the effects of symmetrical and unsymmetrical loading, both vertical, such as an excess of snow on one side, is shown in the two diagrams. The remark regarding Fig. 1 before made, as to taking the maximum stress for the corresponding member on the opposite side, applies here also.

Fig. 5 shows a similar case with a differently designed roof.

Fig. 6 represents one of the transverse trusses used on the New York Elevated Railway, Eighth Avenue Viaduct. They are supported on columns at 1 and 6, and three lines of rails are carried by them, one line in the centre and one equidistant from it on each side, giving rise, according as the lines are all equally weighted by trains, or otherwise, to symmetrical and unsym-

metrical loading. The several stresses produced, which are sufficiently provided for by the scantlings used in the work, are those shown in the two diagrams respectively.

Fig. 7 illustrates the effect of both unsymmetrical and oblique loading, such as might be produced by snow and wind simultaneously.

After the preceding, Fig. 8 needs no explanation, further than to say that, in order to avoid the occurrence of more than two unknown stresses in the computation of the final polygons, the joints are taken in two series from the abutments meeting at the centre.

Fig. 9 needs no remark, except that in this and in similar cases of uneven loading, care must be taken to estimate the unequal reactions *b c* and *c w* correctly. If these are incorrect the diagram will not close, and all the results will be wrong.

Fig. 10 shows how the transverse strains produced by weighting an unbraced arch, the extra and intra-dosal lines of which do not contain the curve of equilibrium due to the load, may be computed by the graphic process.

In the final Fig. 11, all the members under the given loading are found to be in compression, and the joints are dealt with from both abutments to the centre, as in Fig. 8.

The Author believes that in the foregoing examples, by following out in detail each polygon, and connecting the skeleton trusses with them by the notation adopted, he has, if not adding anything new to the graphic theory itself, helped to make it more intelligible to those who wish to understand its practical use.

The Paper is illustrated by several diagrams, from which Plates 8 and 9 have been prepared.

(*Paper No. 1918.*)

"Continuous Girder Bridges."

By THOMAS CLAXTON FIDLER, M. Inst. C.E.

IN applying mathematical theory to the solution of the various questions which arise in the work of designing iron bridges, it is a matter of no small importance to select such a method of calculation as will exhibit within the smallest possible compass the whole conditions of the problem and process of its solution, and will at the same time present the required results in a simple and manageable form. In these respects, the advantages offered by the Graphic or Geometric methods are very great, although perhaps the facility of adaptation which these methods possess may not be so readily appreciated by the mathematician as they are by the engineer or draughtsman who employs them as instruments in working out the elements and details of his design.

In the case, especially, of Continuous Girder Bridges, the formulas deduced by analytical theory are so complex that any simple geometrical solution of the problem, even if less elegant or less rigorously exact, would probably be preferred by most practical men as being far more serviceable for their purposes. The complexity of the theory in this case arises from the fact that when the girder is supported at more than two points, the upward reaction of the supports cannot (as in the case of detached girders) be directly calculated; the external forces acting upon the girder are therefore not all known, and the bending moments cannot be calculated except by reference to the elasticity of the girder. If the girder were inflexible the problem would be insoluble, but the problem is solved by taking into consideration the relation which subsists between the bending strain and the bended form of the girder. This relation may be conveniently expressed or illustrated by graphic construction, and a general geometrical theorem may be deduced which will furnish the means of obtaining a ready solution of the problem—at least in those cases which are of most ordinary occurrence; and the comparative simplicity of this method of dealing with a somewhat difficult question may perhaps be a recommendation in its favour sufficiently strong to warrant a brief description of the process.

1. For the sake of greater simplicity the following conditions, which are generally taken as the basis of calculation, are here also assumed in the first instance, viz.:—

1st. The girder is of uniform depth.

2nd. The flanges are of uniform section.

3rd. The girder is perfectly straight when not subjected to any transverse strain.

4th. The supports are all brought up to the same level, or laid upon one true gradient.

The girder, when placed upon the piers, will therefore exactly touch every one of the supports without bending. The girder will then be bent by the imposition of the load (including its own weight), and must be bent in such reverse curves as to leave unaltered the level of the several points that occur over each support, and the problem will be to find the hogging and sagging curves of the bended girder, and the corresponding hogging and sagging strains.

2. The relation that subsists between the bending strains and the bended form of a girder may be conveniently expressed in either of the following ways:—

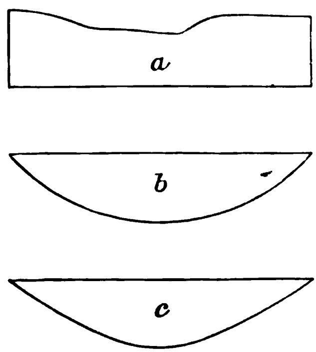
1st. In the case of any girder of uniform depth and with constant or varying section of flange, let a diagram be constructed representing the varying intensity of stress in the flanges, also another diagram representing the varying intensity of load upon the bridge. Then the deflection-curve, or curve of the bended girder, is related to the diagram of stress-intensity in the same manner that the curve of moments is related to the diagram of load-intensity.[1]

2nd. In the case of any girder of uniform depth and uniform section, the diagram of moments is itself a diagram of stress-intensity, and therefore the deflection-curve may be constructed from the diagram of moments in the same way that the latter diagram is constructed from a diagram of load-intensity—that is to say, having first represented the varying intensity of the load by a diagram (*a*), proceed by any of the well-known methods to construct the curve of moments (*b*); then treat diagram (*b*) as representing the varying intensity of an imaginary load, and by a repetition of the same method proceed to construct another curve

[1] This may be otherwise expressed by saying that the curve assumed by the bended girder, is the curve which would be assumed by a flexible chain under a load whose varying intensity is proportional to the intensity of stress in the flanges of the girder.

of moments (c) corresponding to the imaginary load. The curve (c) will be the deflection-curve required, or the actual curve of the bended girder.

3. In the Appendix this proposition is first demonstrated and then applied to two ordinary examples; its application is of course universal for all girders of uniform depth, but the two examples selected are sufficient to lead up to the case of a continuous girder, and a simple graphic method is found by which the elements of the deflection-curve in any span of a continuous girder may be constructed. A comparison of this deflection-curve with the diagram of moments from which it has been constructed shows that, in



every span of a continuous girder, there are a certain pair of "characteristic points" in the diagram of moments, which are so situated that the position of each point above or below the datum line indicates and measures the upward or downward slope of the girder at the adjacent pier; and with the aid of these "characteristic points" the solution of the problem is completed. To illustrate this more clearly, reference may be made to Fig. 2, Plate 10, which is a diagram of bending moments for a continuous girder of three equal spans, and in which the "characteristic points" are marked by small circles. The first and second spans are supposed to be covered with a uniform load, and the parabolic diagrams are drawn for each span as for a detached girder. The "characteristic points" are then fixed by dividing each span into three equal parts, and setting off upon the corresponding ordinates the lengths GH and IK equal to $\frac{2}{3}$ EF. A pair of points are fixed in the same way in the second span, and in every span which is uniformly loaded. When the load is irregular the points are fixed by a simple calculation (as in the span CD). The datum line of the diagram,

from which the bending moments in the continuous girder are to be measured, is the broken line AMND, whose position is at present unknown; and it may be said that to fix the position of this line is the final object of the theory of continuous girders.

But the continuity of the girder over the pier B involves (or rather consists in) the condition that the upward slope of the girder at this point towards C is equal to its downward slope towards A, and it is shown in the propositions appended that the upward slope of the girder towards C is proportional to the ordinate $L L_1$, above the datum line, and that the downward slope of the girder towards A is proportional to the ordinate KK_1 below the datum line. The "characteristic points" K and L to the right and left of each pier are therefore so situated that the datum line must be drawn in from pier to pier at such heights as to pass below the one point and above the other, and at equal distances from each. This adjustment being effected at each pier, the diagram is completed for the whole length of the bridge.[1]

The adjustment of the datum line in such a position as to comply with these conditions is in practice very easily effected, but in order to avoid the necessity of any tentative adjustment, a direct method of geometrical construction is given in Prop. III., which is applicable to any number of equal or unequal spans.

4. It is evident that the method which has been illustrated by the example of the three-span bridge may be applied to any number of equal spans, and that the "characteristic points" may be fixed in the same way for each span, whether heavily or lightly loaded, so long as the load on each span is uniformly distributed; also it has been already remarked that when the load on any span is unevenly distributed the points may be fixed for that span by an easy calculation of the ordinates.

The method may also be applied without difficulty to the following cases, viz.:—

1st. When the spans are not of equal width. In this case it is only necessary to make $\overline{K K_1} \times \overline{A B} = \overline{L L_1} \times \overline{B C}$, and the same at any pier which stands between two spans of unequal width.

2nd. When the supports are not brought to one uniform level, or when any subsidence takes place in the supports. In this case,

[1] In the case of a beam fixed at each end, the slope of the beam at each end is nothing; therefore the datum line must pass *through* the characteristic points. The same thing occurs in the diagram Fig. 4 (Plate 10), in which the side spans of the bridge are covered with a uniform load of $\frac{2}{3}$ the intensity of the load covering the central span, showing that in this case also the girder is horizontal over each of the two intermediate piers.

if any individual pier stands above or below the level of the adjacent supports on each side, the "characteristic points" right and left of that pier are moved downwards or upwards upon the diagram by an amount which is easily calculated when the section of the girder is known.

Suppose a chord line to be drawn between the tops of the two piers A and C, and suppose that the intermediate pier B stands above or below the chord line by the vertical height $\pm s$; and let d denote the depth of the girder.

Also let the diagram of moments be considered as representing, on a certain scale of tons-per-square-inch, the intensity of strength in the flanges.

Then it is shown in the Appendix that the characteristic point K is moved downwards by an amount which is represented on the same scale by the distance $\overline{\mathrm{K}\,\mathrm{K}_2} = \mathrm{E} \times \frac{s}{\mathrm{A\,B}} \times \frac{d}{\mathrm{A\,B}}$, E being the modulus of elasticity in tons-per-square-inch.

5. It is evident that the irregularity last mentioned may be produced by either of the following contingencies:—

1st. Any error in the first adjustment of the several supports in level.

2nd. Any settlement in the foundations or masonry of the piers.

3rd. The expansion and contraction which take place in the tall iron piers of a viaduct.

And it is also evident that similar effects will be produced if the girder is not made perfectly straight, or if a permanent set takes place, or if the continuity of the girder over the piers is imperfectly made. These several contingencies have therefore an important bearing on the design and also on the erection of continuous girder-bridges, and have sometimes been urged as a general objection against the adoption of continuous girders.

The effect of some of these contingencies may, however, be easily calculated beforehand; thus, referring to the expansion and contraction of the iron piers of a viaduct, whose effect is illustrated in Fig. 3 (Plate 10), it will be seen that as the expansion of each pier is proportional to its height, the stress produced will in general be proportional to the ratio $\frac{\text{height of pier}}{\text{span}}$; but this will be largely modified by the relative heights of the successive piers or by the sectional contour of the valley which is crossed by the viaduct. If a chord line Af is drawn as in Fig. 1 between the

bases of alternate piers, the effective expansion of the intermediate pier will be the expansion of the length $\overline{gh}$ intercepted below the chord line, and the stress will be proportional to $\frac{\overline{gh}}{\text{span}}$.

In the example shown in Fig. 1, Plate 10, the height of the piers is nearly one half of the span, and the height gh nearly one-fourth of the span, and the stress due to a total range of temperature of 120° Fahrenheit, as illustrated in Fig. 3, amounts to about $\pm 2\frac{1}{2}$ cwt. per square inch of flange section, the depth of the girder being $\frac{1}{10}$ the span.[1] Other viaducts might be instanced in which the height of the pier bears a much greater proportion to the span than in the case here illustrated, but in which the stress produced by the same range of temperature is no greater than above stated, owing to the concave and approximately parabolic section of the valley, and the simultaneous expansion and contraction of the piers.

The effect produced by the subsidence of one pier is, however, considerably aggravated when the adjacent piers do not partake in the subsidence; this is illustrated by the distortion of the datum line in the diagram Fig. 4, in which the pier B is supposed to have settled 1 inch below its proper level, thus leaving the pier C standing at an elevation of $\frac{1}{2}$ inch above the chord line B D. The stress produced by any given subsidence, or error of level in one pier, will be inversely proportional to the span. It would appear, therefore, that the question of providing against this contingency is of more serious moment in bridges of small span than in larger structures, for there seems to be no valid reason for anticipating that any greater subsidence or error of adjustment would occur in consequence of the piers being spaced at wider intervals. The difficulty of fixing the probable limit of such subsidence in any given case is probably the chief ground of the objection that is sometimes taken against continuous girders; but in regard to such objections it may be remarked that there are many existing engineering structures, such as the columns supporting the turntable of swing bridges, in which a subsidence of 1 inch (if it ever took place) would be attended with far more serious consequences than in a large continuous girder bridge. Yet in such cases it is commonly assumed that the settlement of the supports will be nothing, or almost nothing, and the assumption is in most cases justified by

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[1] In the case of the Kentucky Bridge, whose proportions are similar to those of Fig. 1, some special arrangements were adopted to obviate the apprehended effect of expansion of the piers.

the result of experience. In the case of the Britannia Bridge, the greatest increase of strain that would be produced by a settlement of 1 inch in either of the piers does not amount to more than about 4 cwt. per square inch.

Referring now to the form and adjustment of the girder itself, it is evident that the strains produced by any irregularity in the level of the supports may also be produced by a corresponding irregularity in the form of the unstrained girder; but if the requisite precautions are taken in the erection of the girder, these causes of strain may always be avoided; or if purposely admitted their effects may be easily calculated. By varying the adjustment of the girder and its supports, the strains in a continuous girder may of course be arbitrarily varied to any extent, and if the calculated strains are to represent the strains that actually take effect in the girder, the theory must be consulted in the erection of the work quite as much as in its design. The calculation of strains in the drawing-office and the erection of the work out of doors, cannot be treated as two independent operations which have no relation to each other. The calculation indeed, cannot be made at all except by assuming some particular adjustment of the work, and it will only be true if that adjustment and no other is carried out in practice. The adjustment which is usually assumed as the basis of calculation, is one which in most cases may be conveniently and accurately carried out in the work; but when the method of erection is such that the girder is strained in the course of its construction, cases may sometimes occur in which this particular adjustment cannot be so accurately effected as some others which might be mentioned; and in such cases there appears to be no reason why the first-named adjustment should be rigidly adhered to, but rather that such an adjustment should be assumed as the basis of calculation and aimed at in the construction of the work, as can be most securely and accurately effected, having regard to the proposed method of erecting the bridge.

6. Finally it may be remarked that the geometrical solution above described may be modified and extended to include the case of a girder with varying section of flange; its application to this case being described in outline at the close of the Appendix. In this case the position of the "characteristic points" is moved laterally upon the diagram.

The Paper is accompanied by a tracing, and by numerous sketches in the text from which Plate 10 and the woodcuts have been engraved.

APPENDIX.

For the sake of greater simplicity in the following demonstrations, it will be assumed that the girder is an open skeleton or truss, in which the upper and lower members may be considered as mere lines, their depth being very small as compared with the depth of the girder. It will be seen, however, that the conclusions hold good for any uniform section, the element of deflection due to the shearing stress being as usual neglected. It will also be assumed that the upper and lower members have the same sectional area, so that the neutral axis is in the centre of the depth; where this is not the case, the mean sectional area of the two flanges may be substituted for their actual areas at any given section of the girder. It will further be assumed that the girder is of wrought iron, whose extension or compression under a strain of 1 ton per square inch is equal to $\frac{1}{10000}$th of its length; for any other material it is only necessary to substitute the corresponding modulus of elasticity.

NOTE A.—In any diagram of moments the ordinates represent the bending moments, and are measured on a certain scale of foot-tons. In a girder of uniform depth, the flange stress is also represented by the diagram of moments, the ordinates being measured on a certain scale of tons. In a girder of uniform depth and uniform section the intensity of flange-stress is also represented by the diagram of moments, the ordinates being measured on a certain scale of tons per square inch; the diagram may therefore be used as a diagram of stress or as a diagram of stress-intensity.

PROPOSITION I.

Problem.—The diagram of stress-intensity in any girder of uniform depth being given, it is required to construct the deflection-curve, or to find the slope and deflection of the girder at any point.

In Fig. 5, let B C represent the whole or any portion of the length of the girder, and let A B C D be the diagram of stress-intensity due to a positive bending stress, *i.e.*, let the ordinates A B, &c., represent the intensity of tensile stress in the upper member, and of compressive stress in the lower member. Also in Fig. 6, let the straight line B C_1 represent the original unbended line of the girder, and let the flexure commence at B, so that the line B C_1 will be a tangent to the deflection-curve at that point; then the deflection C C_1, and the slope of the tangent G C, may be found as follows:—Suppose the diagram of stress-intensity to represent the varying intensity of an imaginary load. The slope of the tangent G C will be proportional to the weight of the imaginary load, or to the area A B C D. The tangent G C will intersect the tangent B G at the centre of gravity of the imaginary load. The deflection C C_1 will be proportional to the moment of the imaginary load about the point C.

Demonstration.—For let the diagram of stress-intensity be divided into a number of parallel bands of indefinitely small width by the vertical ordinates *e e*, *f f*, &c., as in Fig. 7, and let the side of the straight girder be divided into the same number of bays by the vertical lines *e' e'*, *f' f'*, &c., which in the bended girder will become radiated like the joints of an arch, as in Fig. 8.

Fig. 5.

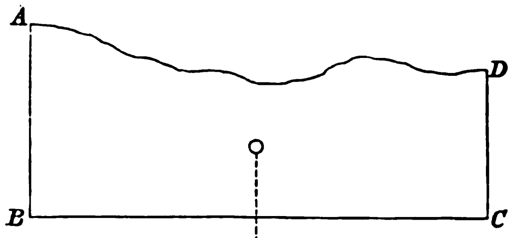


Fig. 6.

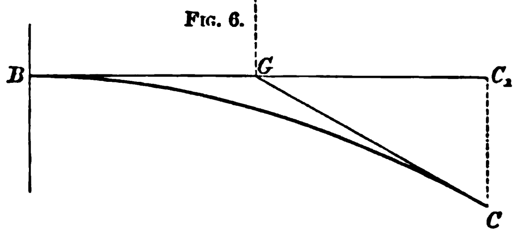


Fig. 7.

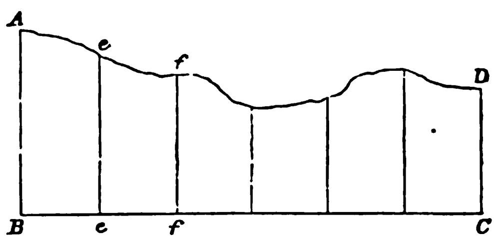
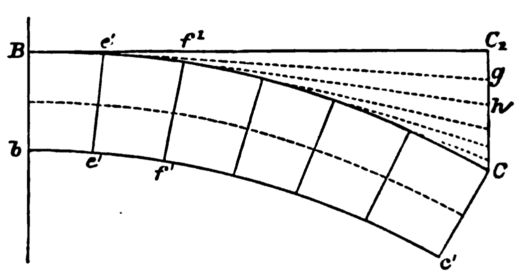


Fig. 8.



In the bended girder the upper member B e' will be extended by an amount which is proportional to the length B e' multiplied by the intensity of tensile stress, or proportional to the area of the band A B e e in the diagram of stress-intensity. The lower member of the first bay will be shortened by a like amount, and the inclination of the normal e' e', or the inclination of the tangent e' g will be measured by the extension of the upper member divided by half the depth of the girder. The element of deflection C_1 g, due to the stress on the first bay of the girder, will therefore be proportional to the area of the band A B e e, multiplied by its distance from the point C.

In the same way, the second line f' f' will receive an additional inclination proportional to the area of the band of stress e e f f, and finally the inclination of the normal C c, or the slope of the girder at C will be equal to the sum of all the inclinations, and will therefore be proportional to the total area of the

FIG. 9.

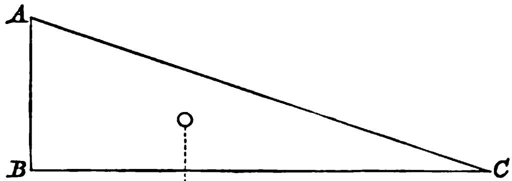


FIG. 10.

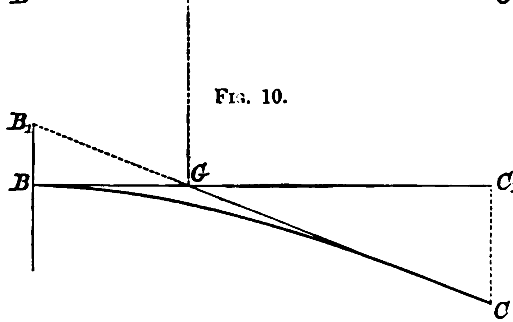


diagram A B C D; while the total deflection C_1 C will be the sum of the deflections $C_1\,g + g\,h +$ &c., and therefore proportional to the area of the diagram multiplied by the distance of its centre of gravity from the point C.

If l = the length of a wrought-iron girder, and d = the depth, it will be seen that the slope of the tangent G C = $\frac{\text{mean intensity of stress}}{\text{10,000 tons per square inch}} \times \frac{l}{\frac{1}{2}\,d} = \frac{\text{area of diagram}}{5000\,d}$.

Deflection C_1 C = slope × distance G C = $\frac{\text{moment of diagram}}{5000\,d}$.

Example 1.—To find the deflection of a cantilever of uniform section loaded at the end.

Let the triangle A B C in Fig. 9 represent the diagram of stress-intensity; the area of the triangle being $\overline{\text{A B}} \times \frac{l}{2}$, the slope of the tangent G C in Fig. 10 will

be $\overline{AB} \times \frac{l}{10,000\,d}$. The deflection $C\,C_1$ measured below a tangent drawn through the point B will be equal to the slope of tangent $\times \frac{2}{3}\,l$, or

$$\text{Deflection } \overline{C_1\,C} = \frac{2}{3}\,\overline{A\,B} \times \frac{l^2}{10,000\,d} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The deflection $B_1\,B$ measured below a tangent drawn through the point C will be half this amount,

or
$$\text{Deflection } \overline{B_1\,B} = \frac{1}{3}\,\overline{A\,B} \times \frac{l^2}{10,000\,d} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Example 2.—To find the deflection of a girder of uniform section, supported at each end, and covered with a uniformly distributed load.

Let the parabola B F C in Fig. 11, represent the diagram of stress-intensity,

FIG. 11.

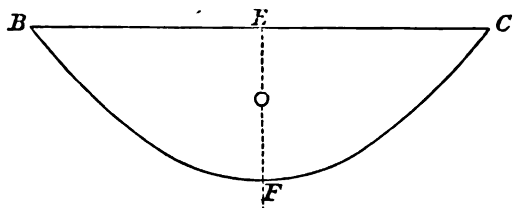
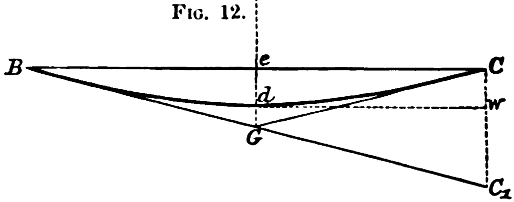


FIG. 12.



in which the ordinate E F represents the maximum intensity of stress at the centre of the girder, and let Fig. 12 represent the deflection-curve.

If now it is required to find the central deflection of the girder $e\,d$ below the chord line B C, this will of course be equal to the ordinate C w measured above the tangent $d\,w$, and will be proportional to the moment of the half parabola E F C; but for the present purpose it is more important to find the deflection or ordinate $C\,C_1$ measured from the tangent $B\,G\,C_1$ drawn through the point B; the inclination of this tangent with the chord line B C will of course be fixed as soon as $C\,C_1$ is known. The area of the whole parabola will be $\frac{2}{3}\,\overline{E\,F} \times l$, and the angle or inclination $C\,G\,C_1$ is therefore $\frac{2}{3}\,\overline{E\,F} \times \frac{l}{5000\,d}$. The ordinate $C\,C_1$ = the inclination $C\,G\,C_1 \times \frac{l}{2}$,

or
$$\text{Deflection } \overline{C\,C_1} = \frac{2}{3}\,\overline{E\,F} \times \frac{l^2}{10,000\,d} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Example 3.—To draw the deflection-curve of any span of a continuous girder, the span being covered with a uniform load.

In Fig. 13 let the positive and negative moments, and also the corresponding stress-intensities, be represented by the ordinates above and below the datum line M N. In Fig. 14 let the line B C_1 represent a tangent drawn through the deflection-curve at the pier B; the inclination of this line is not known, but will be fixed as soon as C_1 C or the ordinate to the deflection-curve at C has been found. Find the horizontal distance from the pier to the centre of gravity of the area B M S, which fixes the intersection of the tangents *e g* and B C_1, and draw the tangent *e g* with an inclination C_1 *e g* proportional to the area B M S, making the height C_1 *g* proportional to the moment of that area about the pier C.

Fig. 13.

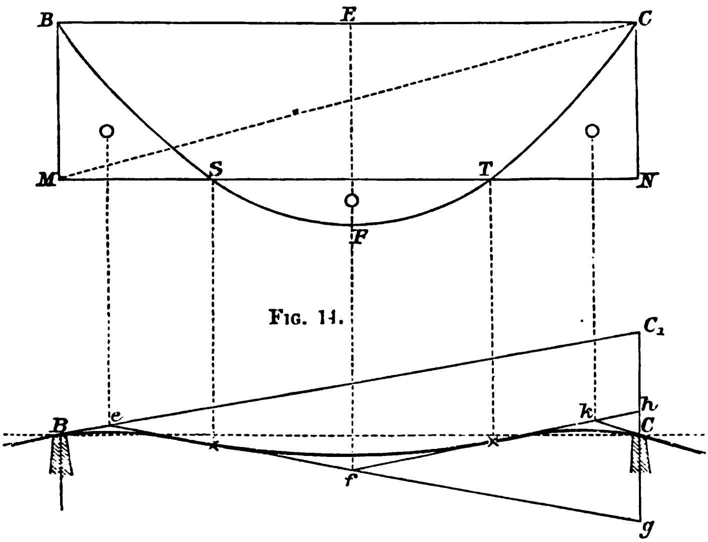


Fig. 14.

In the same way draw the tangent *f h* intersecting the tangent *e g* at the centre of gravity of the area S F T, and with an inclination proportional to that area, so that the height *g h* is proportional to the moment of that area about the pier C. Again, find the centre of gravity of the area T C N, and draw the tangent C *k* intersecting the tangent *f h* in the point *k*, the inclination or angle *h k* C being proportional to the area T C N.

The ordinate C_1 C will be equal to $C_1\,g - g\,h + h\,C$, and therefore proportional to the algebraical sum of the moments of the three areas B M S, S F T and T C N, and therefore proportional to the moment of the trapezoid B M N C minus the moment of the parabola B E C F. The trapezoidal area may be divided into the two triangles B M C and C M N, for which triangular diagrams the deflection has already been determined as well as for the parabolic diagram, and applying the formulæ (1) (2) and (3) it is evident that the deflection ordinate

$$\overline{C_1 C} = \left(\frac{2}{3}\overline{B\,M} + \frac{1}{3}\overline{C\,N} - \frac{2}{3}\overline{E\,F}\right)\frac{l^2}{10{,}000\,d} \quad . \quad . \quad (4)$$

The upward inclination of the tangent B C_1 at the pier B will therefore be

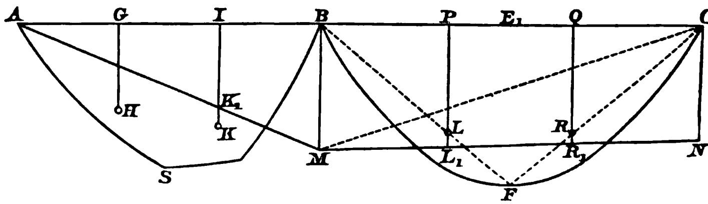
$$\frac{C_1\,C}{B\,C} = \left(\frac{2}{3}\,\overline{B\,M} + \frac{1}{3}\,\overline{C\,N} - \frac{2}{3}\,\overline{E\,F}\right)\frac{l}{10{,}000\,d} \quad . \quad . \quad (5)$$

In the same way the upward inclination of the girder at the pier C (upward towards B) will be

$$\frac{B\,B_1}{B\,C} = \left(\frac{2}{3}\,\overline{C\,N} + \frac{1}{3}\,\overline{B\,M} - \frac{2}{3}\,\overline{E\,F}\right)\frac{l}{10{,}000\,d} \quad . \quad . \quad (6)$$

Corollary.—The slope of the girder at either pier is indicated in the diagram of moments, and may be measured upon the diagram of stress-intensities in the following manner, viz.: Divide the span into three equal parts, as in Fig. 15,

FIG. 15.



and draw the corresponding ordinates P L_1 and Q R_1 intersecting the datum line in the points L_1 and R_1. On each of these ordinates set off P L = Q R = $\frac{2}{3}$ E F.[1] Then the slope of the girder at B and at C will be proportional to the ordinates L L_1 and R R_1 respectively: and these ordinates, taken on the scale of stress-intensities and multiplied by $\frac{l}{10{,}000\,d}$, will measure the slope of the girder at the points B and C.

For by the well-known property of the triangles B M C and C M N, it is evident that

$$P\,L_1 = \frac{2}{3}\,\overline{B\,M} + \frac{1}{3}\,\overline{C\,N}, \text{ and that}$$

$$Q\,R_1 = \frac{2}{3}\,\overline{C\,N} + \frac{1}{3}\,\overline{B\,M}; \text{ also by construction}$$

$$P\,L = Q\,R = \frac{2}{3}\,\overline{E\,F}.$$

Therefore

$$L\,L_1 = \frac{2}{3}\,\overline{B\,M} + \frac{1}{3}\,\overline{C\,N} - \frac{2}{3}\,\overline{E\,F}$$

$$R\,R_1 = \frac{2}{3}\,\overline{C\,N} + \frac{1}{3}\,\overline{B\,M} - \frac{2}{3}\,\overline{E\,F}.$$

And comparing the values found for the slope of the girder in (5) and (6), it is evident that if the diagram Fig. 15 is taken as a diagram of stress-intensities, it follows that

$$L\,L_1 \times \frac{l}{10{,}000\,d} = \text{slope of girder at pier B (upwards).}$$

$$R\,R_1 \times \frac{l}{10{,}000\,d} = \text{slope of girder at pier C} \quad ,,$$

[1] This may be done by drawing the straight lines B F and C F to the vertex of the parabolic curve intersecting the ordinates in the required points L and R.

Note B.—For the sake of brevity, the points L and R will be termed the "characteristic points" in the diagram of stress-intensities for the span B C. A pair of "characteristic points" may be found in the diagram of every span as soon as the distribution of the load is known. If the load is irregularly distributed upon the span A B, let the irregular curve A S B represent the corresponding diagram of moments or stress-intensities; then by parity of reasoning, it is only necessary to make G H equal to the height of a rectangle, whose length is A B, and whose moment about the pier B is equal to the moment of the diagram A S B, or if m = moment of irregular diagram about the pier B, and n = moment of same about the pier A, make $\overline{\text{G H}} \times \frac{l^2}{2} = m$, or $\text{G H} = \frac{2\,m}{l^2}$, and $\text{I K} = \frac{2\,n}{l^2}$.

Then H and K will be the "characteristic points" for the diagram, and the downward slope of the girder at $\text{B} = \overline{\text{K K}_1} \times \frac{\overline{\text{A B}}}{10{,}000\,d}$, the ordinate K K_1 being measured below the datum line A M.

Proposition II.

Theorem.—When all the supports of a straight continuous girder are fixed at the same level, the pair of "characteristic points" to the right and left of each pier will be situated on opposite sides of the datum line of the diagram, and the ordinates of those points measured above and below the datum line will be inversely proportional to the respective spans. That is to say, in the diagram Fig. 15 already referred to, $\overline{\text{L L}_1} \times \overline{\text{B C}} = -(\overline{\text{K K}_1} \times \overline{\text{A B}})$.

Fig. 15.*

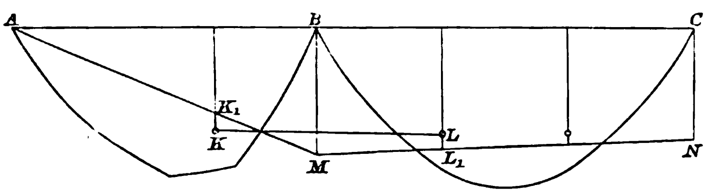
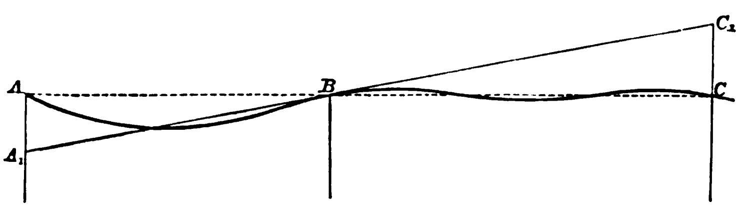


Fig. 16.



For let A B C in Fig. 16 be a horizontal line joining the summits of the three piers, and let $\text{A}_1\text{B C}_1$ represent a tangent to the deflection-curve at the point B, then whatever may be the unknown inclination of this tangent, it is evident that

$A\,A_1 : A\,B = C\,C_1 : B\,C$, and it has been shown that in the diagram of stress-intensities or moments, Fig. 15,

$$\overline{L\,L_1} \times \overline{B\,C} \propto \frac{C\,C_1}{B\,C} \text{ and } \overline{K\,K_1} \times \overline{A\,B} \propto \frac{A\,A_1}{A\,B}.$$

Therefore
$$\overline{L\,L_1} \times \overline{B\,C} = -(\overline{K\,K_1} \times \overline{A\,B}).$$

Note C.—When the spans are of equal length, of course $L\,L_1 = -K\,K_1$, &c.

Note D.—The above proposition will evidently apply also to a girder laid upon one uniform gradient; but if the supports are not in one true plane, the algebraical sum $(\overline{L\,L_1} \times \overline{B\,C}) - (\overline{K\,K_1} \times \overline{A\,B})$ will not be $= 0$, but will have a value which may be determined. For practical purposes, however, it will be most convenient to treat this question by changing the position of the "characteristic points" upon the diagram of stress-intensity, so that the terms of Proposition II. may apply to the altered position of the points.

Fig. 17

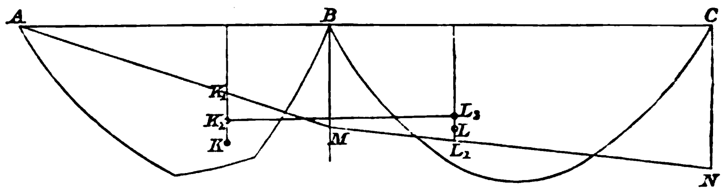
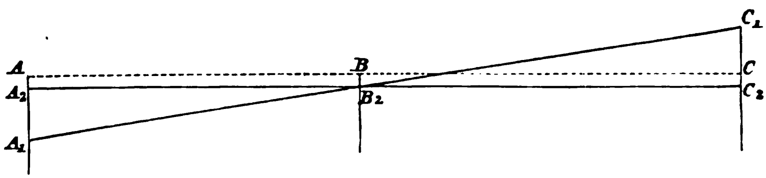


Fig. 18.



Thus in Fig. 18, suppose the pier B to have sunk below the chord line A C by the vertical distance $B\,B_2 = S$, and let the line $A_1B_2C_1$ represent as before, the tangent to the deflection-curve. Then $\frac{A\,A_1}{A\,B}$ will no longer be equal to $\frac{C\,C_1}{B\,C}$, but if a horizontal line $A_2\,B_2\,C_2$ be drawn through B_2 parallel to A C, the equation of slope will be

$$\frac{C_1\,C_2}{B\,C} = -\frac{A_1\,A_2}{A\,B}, \text{ or } \frac{C_1\,C}{B\,C} + \frac{S}{B\,C} = -\left(\frac{A\,A_1}{A\,B} - \frac{S}{A\,B}\right).$$

In the diagram of stress-intensity, Fig. 17, let K and L be the "characteristic points" which have been fixed in the manner before described, so that $\frac{C_1\,C}{B\,C} =$
$\overline{L\,L_1} \times \frac{\overline{B\,C}}{10{,}000\,d}$

Above the point K set off, on the scale of stress-intensity, the length $\overline{K K_2} = 10{,}000 \frac{d}{\overline{A B}} \times \frac{S}{\overline{A B}}$, and above L set off $L L_2 = 10{,}000 \frac{d}{\overline{B C}} \times \frac{S}{\overline{B C}}$, so that

$$(\overline{L_1 L} + \overline{L L_2}) \cdot \frac{\overline{B C}}{10{,}000\, d} = \frac{\overline{C_1 C}}{\overline{B C}} + \frac{S}{\overline{B C}};$$

then the equation of slope will be expressed upon the diagram of stress-intensity by

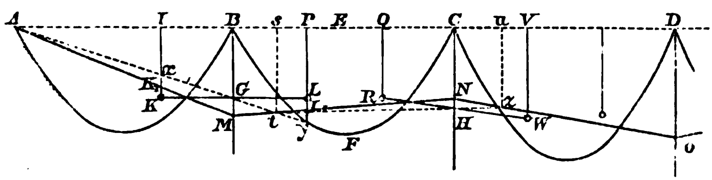
$$\overline{L_1 L_2} \times \overline{B C} = -(\overline{K_1 K_2} \times \overline{A B}),$$

so that the original points K and L are now replaced by the "characteristic points" K_2 and L_2, which indicate the true inclination of the girder, or its inclination to the chord B C. And *vice versâ* if any pier stands above the chord line joining the adjacent piers, the "characteristic points" right and left of that pier will be moved in the same way into a lower position.

Proposition III.

Problem.—In a continuous girder of uniform section, supported at any number of equal or unequal intervals by piers fixed at equal or unequal levels, to draw by direct construction the diagram of moments for any regular or irregular load.

Fig. 19.



On the straight line A B C D in Fig. 19, construct the curve of moments B F C, &c., for each span as for a detached girder. Divide each span A B, B C, &c., into three equal parts, and upon the corresponding ordinates P L, Q R, &c., set off the position of the "characteristic points" in the manner before described, *i.e.*, if the load is uniformly distributed upon any span B C, make P L and Q R each equal to $\frac{2}{3}$ E F; if the load is irregular calculate those ordinates as described in Note B, Proposition I.; if the levels of the piers are irregular, correct the ordinates as described in Note D, Proposition II. Draw K L, R W, &c., joining the pair of points situated to the right and left of each pier, and intersecting the verticals B M, C N, &c., in the points G and H.

Assuming, in the first place, that the spans are all of equal width, the condition to be fulfilled in drawing the datum line A M N O is that $L L_1 = - K K_1$, and so on at each pier of the bridge. Divide the length B P into two parts, making $\frac{P s}{B s} = \frac{A I}{A B} = \frac{A I}{B C}$, and draw the vertical *s t*. Then starting from A draw through G the straight line A G *t*, intersecting *s t* in *t*. The point *t*

will be situated in the datum line M N. Then starting again from the ascertained point t proceed in the same way at the next pier, *i.e.*, divide C V into two parts, making $\frac{V\,u}{C\,u} = \frac{s\,Q}{s\,C}$, and draw the vertical $u\,z$; then through H draw the line t H z, intersecting $u\,z$ in z. The point z will be situated in the datum line N O. Commencing also at the other end of the bridge, proceed in the same manner from each end towards the centre, thus fixing two points in the datum line of the central span. All the datum lines can then be easily completed.

Demonstration.—For let the line A G t be prolonged until it intersects the vertical P y in y; then $L_1\,t\,y$ and G t M are similar triangles, and

$$\frac{L_1\,y}{G\,M} = \frac{P\,s}{B\,s} = \frac{A\,I}{A\,B}.$$

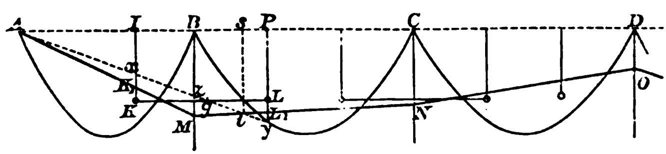
But $$\frac{K_1\,x}{G\,M} = \frac{A\,I}{A\,B}; \text{ therefore } K_1\,x = L_1\,y.$$

Also the triangles L G y and K G x are similar triangles, and K G = L G, therefore L y = K x.

Therefore $$L\,y - L_1\,y = K\,x - K_1\,x, \text{ or } L\,L_1 = K\,K_1.$$

When the span A B is not equal to the span B C, as in Fig. 20, join K L as before and divide K L into two parts, making K g : L g = B C : A B. Then the condition to be fulfilled is that $L\,L_1 \times B\,C = -(K\,K_1 \times A\,B)$, or $L\,L_1 : L\,g = K\,K_1 : K\,g$.

FIG. 20.



Divide B P into two parts, making $\frac{P\,s}{B\,s} = \frac{A\,I}{B\,C}$, and draw the vertical $s\,t$; then from A through the point g draw the line A z g t intersecting B M in z, and intersecting $s\,t$ in t. The point t will be situated in the datum line M N.

The demonstration is similar to the foregoing,

for $$\frac{L_1\,y}{z\,M} = \frac{P\,s}{B\,s} = \frac{A\,I}{B\,C}.$$

and $$\frac{K_1\,x}{z\,M} = \frac{A\,I}{A\,B} = \frac{L_1\,y}{z\,M} \times \frac{B\,C}{A\,B},$$

also $$K\,x = L\,y \times \frac{B\,C}{A\,B}.$$

Therefore $$K\,K_1 = L\,L_1 \times \frac{B\,C}{A\,B}.$$

Note E.—When the girder is constructed with flanges of varying sectional area, as indicated, for example, in the diagram Fig. 21, the case may be treated by an extension of the method described in the preceding propositions. The following may be suggested as an outline:—

In the diagram of moments, Fig. 22, it is evident that the stress-intensity due to any bending moment X W is equal to the sum of the stress-intensities due to the three moments X Y + Y Z − Z W; and if three diagrams of stress-intensity are constructed to correspond with the three diagrams of moments B M N C B N, and B E C F, the algebraical sum of the moments of these diagrams of stress-intensity about the point C will be proportional to the upward slope of the

FIG. 21.

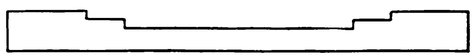
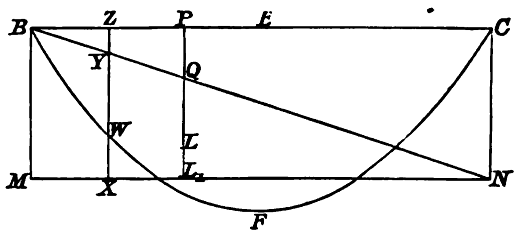


FIG. 22.



girder at B. The values of B M and C N are not known, but assume for each a unit value (1 foot-ton), and construct the corresponding diagrams of stress-intensity, Figs. 23 and 24, and having found the centre of gravity and the area

FIG. 23.

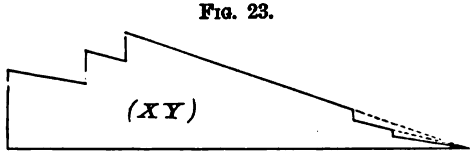
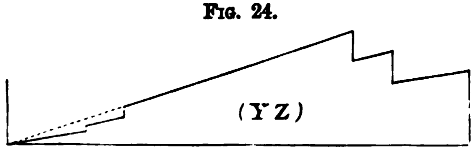


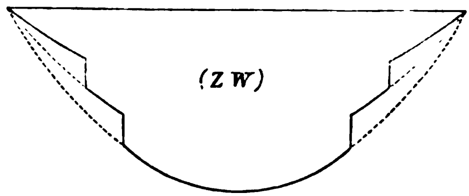
FIG. 24.



of each of these figures, let their respective moments about the pier C be denoted by $\phi_1 \cdot \frac{l^2}{2}$ and $\phi_2 \cdot \frac{l^2}{2}$.

Then whatever may be the values of B M and C N the moments of the corresponding diagrams of stress-intensity will be $\overline{BM} \cdot \frac{\phi_1 l^2}{2}$ and $\overline{CN} \cdot \frac{\phi_2 l^2}{2}$. Also, for the parabolic diagram of moments B E C F, construct the diagram of stress-intensity, Fig. 25, and calculate its moment about C. Let this moment

FIG. 25.



be $= \overline{EF} \times \frac{\phi_2 l^2}{2}$. Then, as shown in Proposition I., the upward slope of the girder at B will be $(\phi_1 \cdot \overline{BM} + \phi_2 \cdot \overline{CN} - \phi_2 \cdot \overline{EF}) \frac{l}{10{,}000\, d}$. Divide the span B C into two parts, making

$$\overline{PC} : \overline{BP} = \phi_1 : \phi_2.$$

Then
$$L_1 Q = BM \cdot \frac{PC}{BC} = \overline{BM} \cdot \frac{\phi_1}{\phi_1 + \phi_2}$$
$$QP = CN \cdot \frac{BP}{BC} = \overline{CN} \cdot \frac{\phi_2}{\phi_1 + \phi_2}.$$

Finally set off
$$PL = \overline{EF} \cdot \frac{\phi_2}{\phi_1 + \phi_2}.$$

Then
$$LL_1 = \overline{L_1 Q} + \overline{QP} - \overline{PL} = \frac{\phi_1 \cdot \overline{BM} + \phi_2 \cdot \overline{CN} - \phi_2 \overline{EF}}{\phi_1 + \phi_2},$$

and
$$LL_1 \ (\phi_1 + \phi_2) \frac{\overline{BC}}{10{,}000\, d} = \text{upward slope of girder.}$$

Proceeding in the same way, a pair of points may be found to the right and left of each pier united by an equation of the form

$$\overline{LL_1} \cdot (\phi_1 + \phi_2) \cdot \overline{BC} = - \overline{KK_1} \cdot (\theta_1 + \theta_2) \cdot AB,$$

and the datum line may then be fixed in position by a method proceeding upon similar principles to those already described in Proposition III.

(*Paper No. 1912.*)

"On the Preservation of Iron by one of its own Oxides."

By Benjamin Howarth Thwaite, Assoc. M. Inst. C.E.

When iron is exposed to contact with ordinary moist atmospheric air, it unites with the oxygen of the latter, to form two varieties of oxide of iron; in the first instance, the ferous oxide (Fe O), which becomes rapidly converted into another, or the second variety, the ferric oxide (Fe_2O_3). If a piece of iron is exposed to oxidizable influences sufficiently long, its entire substance will become oxidized; for as soon as the superficial film of oxide on the surface of the iron becomes converted into the second variety, or ferric oxide, part of its oxygen is transmitted to the metallic surface beneath it to form ferrous oxide, and this latter also becomes in its turn converted into ferric oxide, and again transfers its oxygen to the still remaining metallic iron; and this process goes on continuously until the whole of the iron becomes oxidized. Hence, if iron is not protected from this oxidation, corrosion, or action of decay, its strength becomes in time seriously impaired. As will be seen from the formula[1] (arranged by the Author and based on a series of experiments on the action of the oxidation of iron, in order to ascertain the metallic life of iron with a tolerable degree of exactitude), it appears that a bar of wrought iron, 4 inches × 1 inch, subjected to the corrosive atmospheric influences of a manufacturing city, would be entirely corroded away in a little over a single century.

Fortunately, however, besides the two combinations of iron with oxygen already mentioned, there is a third, or the magnetic oxide Fe_3O_4, a most stable oxide, and, as in the examples of the oxides of zinc and copper, once properly formed of a certain thickness, it arrests further oxidation of the iron. It is found in a natural state on the shores of New Zealand, in the form of black titaniferous sand, and although the sea water is constantly washing over it, its stability is apparently unaffected. Lavoisier is credited with the discovery of the artificial formation and stable properties of the magnetic oxide, and the late Mr. Robert Mallet, M. Inst. C.E.,

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[1] Molesworth's "Pocket Book of Engineering Formulæ," twenty-first edition, p. 33.

discovered it during one of his experiments. Berthier noticed it when iron was subjected to highly-heated air, and Thirault is said to have produced the magnetic oxide in 1860, in a very peculiar manner. A modification of Thirault's process is now adopted by gunmakers, who, by means of processes, although long and tedious, succeed in obtaining a most beautiful coating of oxide.

The Russian sheet iron is covered with a thin and rather pliable film of this magnetic oxide, but whether this coating of oxide was originally applied by accident or intention it is impossible to say. An interesting Paper, by Dr. Percy, F.R.S., Hon. M. Inst. C.E., "On the Protection from Atmospheric Action which is imparted to Metals by a coating of certain of their Iron Oxides respectively," was read at the meeting of the Iron and Steel Institute, in Newcastle-upon-Tyne, in September, 1877.[1] In Russia and in the United States common use is made of this sheet iron for covering locomotive-boilers and steam-cylinders, as well as for roofing purposes. Some years ago Professor Barff, F.C.S., whilst engaged in experiments in peat charring, noticed the formation of this peculiar oxide, in a pipe conveying highly-heated steam, and observed its preservative action on the iron. He at once commenced a series of experiments and investigations, which resulted in the elaboration of a process for producing magnetic oxide, for the purpose of preserving the surfaces of iron. Professor Barff's process is a practical adaptation of Lavoisier's principle. In his specification Professor Barff describes the process as follows:—"In carrying out my invention, I place the objects composed of iron or steel in a muffle, or chamber, so constructed as that it may be in part wholly closed, and so that the contents of the interior of such muffle or chamber may be raised, by means of external heat, to an elevated temperature, and when the objects or articles have acquired a temperature sufficiently elevated to cause the decomposition of steam or aqueous vapour when brought into contact therewith, I inject the same, and continue the action of the steam, or the aqueous vapour, until the desired protective film or coating of oxide has been produced." Plate 11, Fig. 1, represents the experimental apparatus used by Professor Barff in his primary investigations—*a*, treating chamber; *b*, coil steam-generator and superheater; *c*, furnace; *d*, water-supply pipe; *e*, hydrogen escape-pipe. Fig. 2 represents the practical apparatus, subsequently adopted by Professor Barff. It will be seen

[1] "The Journal of the Iron and Steel Institute," 1877, pp. 450–460; also "Engineering," vol. xxiv., July–Dec. 1877, pp. 304–305.

that the muffle *a* is in this instance a brick chamber (about 6 feet long), beneath which is fixed an ordinary fire-grate, *b*. The heat of this fire passes both under and round the brick chamber, and thence to the chimney. Alongside this chamber is placed the steam-generator *c*, beneath which, and directly over the fire-grate *d*, is placed a coiled steam-superheater *e*, from which the steam, highly superheated, issues direct into the brick chamber or muffle. The hydrogen, the result of the decomposition of the steam, is led by the pipe *f* to the underside of the fire-grate, where it is consumed. On hearing of Professor Barff's process, it occurred to Mr. George Bower that highly-heated air might possibly be used with success for obtaining a coating of magnetic oxide; Mr. Bower made a series of experiments with air as an agent, and a sample of iron, that was subjected to one of Messrs. Cochrane's hot-blast stoves, was found to have a most decided and adherent coating of magnetic oxide. The first furnace devised for carrying out the air process consisted of an externally-heated chamber, in which the iron articles to be treated were placed. When the iron articles had attained the temperature of oxidation, a few cubic feet of ordinary atmospheric air were blown into the chamber, which was closed, and the iron then entered into combination with the oxygen of the air, a thin film of magnetic oxide being formed on the metal. Fresh air was admitted from time to time, to replenish the oxygen appropriated by the iron, until the requisite thickness of oxide was attained. The difficulty and expense of the application of external heat were so great that it occurred to Mr. Bower's son, who was conducting experiments, that if internal application of heat could be substituted, and the coating of magnetic oxide produced simultaneously with the action of heating, by a series of oxidizing and deoxidizing operations, the process would be much simplified, be more effective, and far less costly. Elaborate experiments were conducted with this aim, and the results far exceeded anticipation. On the basis somewhat of a special furnace, devised and arranged by the Author, Mr. Anthony S. Bower developed a furnace for carrying out this process. In Plate 11, Figs. 3, 4, and 5 represent plans and sections of this furnace. The combustible gases are generated in the three producers, *a*, *a*, and *a* (in the furnaces first designed, an ordinary single Siemens producer, with inclined plates, was used; but owing to the irregular supply and quality of the gas, it was decided to adopt three, of the form shown). By this arrangement a regular plenum of gas can always be obtained; moreover, the producers are admirably adapted to the form of

the furnace. They not only act as buttresses to resist the thrust of the furnace-arch, but they prevent wasteful radiation. Coals are charged through specially devised plug-hoppers. The plugs, in being withdrawn, permit the coals to fall into the producers with a minimum escape of gas. The Siemens balanced coal charging-boxes were tried, but they were abandoned in favour of the form described. The gases, evolved by the distillation of the coal, pass over the partition walls *b*, descending by the down-cast *c*, in which is fixed a regulating valve *d*. The gas then passes along the horizontal flue *f*, to the mouth of the combustion-chamber *g*, when it meets the current of heated air ascending from the recuperators by the port *h*. Combustion here ensues, perfect mixing and oxidation of the gases being attained by the series of intercepting chequer walls *i*; the products of combustion then pass into the side flue *j*, where they ascend into the furnace or muffle, by means of or through the ports *k*. The products of combustion descend from the muffle by the ports *l*, into the side flue *m*, passing from thence into the recuperator, where, by going round the air-tubes *n*, of fireclay, they transmit their heat to the air flowing to support combustion. The products of combustion then escape into the chimney flue *o*. The air passes into the recuperators by means of the regulating valve *p*, and after flowing through the whole length of the tubes in the recuperator chamber twice, it ascends into the port *h*, where it meets the combustible gases coming from the producers.

The cast-iron articles to be treated are placed in the chamber or muffle, and gradually heated by combustion of producer-gas within the chamber, up to the temperature of oxidation, say 1,600° Fahrenheit. The oxidizing process is then commenced, first by submitting the iron to an oxidizing flame, that is to say, by allowing highly-heated air in excess of that necessary for combustion to enter the furnace. The oxygen of this air in excess enters into a double combination with the iron. On the immediate surface of the iron a film or coating of the magnetic oxide (Fe_3O_4) is formed, and over this a film of sesquioxide (Fe_2O_3). This oxidizing operation generally occupies about twenty minutes. The air-valve is then entirely closed, and the combustible gases from the producers (carbonmonoxide, &c.) are allowed to enter unconsumed into the muffle. By this operation, a deoxidizing one, the sesquioxide is converted into the magnetic oxide; this deoxidizing operation generally occupies from fifteen to twenty-five minutes, the duration entirely depending upon the quality of the coal-gas. The richer it is in carbon the less the time required to effect the

deoxidizing operation. The air-valve is now opened, and another double combination of oxygen and iron effected, which, by another deoxidizing operation, is reduced to one combination of Fe_3O_4, the magnetic oxide. It will be understood that by repeating the alternate operations of oxidation and deoxidation sufficiently often the entire metal could be oxidized.

The duration of the process depends upon the size, number, and intended use of the articles. For instance, only six double-oxidizing and deoxidizing periods are necessary for articles intended for internal or indoor use. For articles intended to be subjected to external atmospheric influences, from ten to twelve double periods of oxidation and deoxidation are necessary. Owing to the great sensitiveness of wrought malleable iron and steel to oxidizable influences, the Bower process produces the coating of oxide in these varieties too rapidly, and it is not sufficiently uniform or adherent; and the Barff process has been found by experience to be more satisfactory for producing the magnetic oxide coating on the surfaces of malleable wrought iron and steel.

However the two inventors combined their respective processes, and a furnace, having the economic features of the Bower furnace, was designed to effect the Barff process. This furnace is shown in Plate 11, Figs. 6, 7, 8, 9, and 10; *a a a* are three gas-producers; the gas generated therein passes over the partition or division walls, descending by the downcast *b*, where its flow can be regulated by the damper *c*. The air to support combustion enters by the regulating air-inlet valve *d*, and combustion takes place at the point *e*. The flow of the products of combustion can be directed either over the muffle *f*, by the side flue *g*, and then be turned into the chimney flue, or by withdrawing the damper *h* directly on to the steam-superheater *i*, or by closing the damper *h* and withdrawing the damper *j*, the products of combustion can be directed immediately on to the steam superheater, without having to pass over the muffle.

In the preliminary experiments great difficulty was found in obtaining a satisfactory and durable form of steam-superheater. Circular coils of lap-welded steam-pipes, as shown in Fig. 2, were first tried, but, although effective as superheaters, their cost and liability to stoppage, the necessity of frequent renewal, and the rapid oxidation of the wrought iron, were grave objections, and cast iron was used in the form of a rectangular casing of the whole length of the furnace, and filled with small cast-iron balls. In order to prevent the oxidation of the casing its outer sides were grooved, to retain a refractory lining of a mixture of silicate of soda

and fire-clay; but this lining soon commenced to crack and flake off on continuous exposure to the flame. Further, the oxidation and expansion of the cast-iron balls produced fracture in the outer casing; in other respects this form of superheater gave highly satisfactory results. The form of superheater now adopted is shown in Plate 11, Figs. 6, 7, 8, 9, and 10. It consists of a cast-iron casing, rectangular in section, having a longitudinal division dividing the casing into two parts. The steam entering the lower division is compelled to traverse the whole length of the superheater twice before it can escape; to increase the heating surface the cast-iron casing is filled up with broken pieces of fire-clay of irregular size; the sides of the cast-iron casing are protected from actual contact with the flame by means of fire-clay tiles. The superheater can be renewed without disturbing any part of the structure or cooling down the furnace, a great desideratum, as the latter operation is very detrimental to the condition of the furnace. The superheater is connected to the muffle by means of an expansion coil (*k*, Fig. 6), which permits the superheater to expand and contract. It further serves as a pyrometer, as by the relative visible temperature of the coil, which can be visually examined by removing a portion of the loose coal ashes which cover it, the temperature of the steam entering the muffle can be ascertained.

A great difficulty was at first experienced in arranging a satisfactory rolling-carriage, for carrying into and out of the muffle the articles to be oxidized; but the difficulty has been solved by the arrangement shown in Figs. 11 and 12, consisting of a cast- or wrought-iron table having equally distributed perforations over its entire surface, and having horizontal cast- or wrought-iron webs or ribs on its underside, which keep the differential rolling arrangements in position. This latter consists of a series of double rollers, their peripheries running in the channels formed on the underside of the table, and upon the false cast-iron base-plate forming the muffle floors. The rollers are held together by wrought-iron bars. By this arrangement, although there is no part of the rolling apparatus actually bolted, the carriage runs as freely and firmly at a temperature of bright red heat as when cold, and each part can easily be removed, and renewed.

A point of importance, to ensure the success of the process, is the arrangement of the articles on the table before treatment. If placed indiscriminately and carelessly upon each other, they may become distorted during the process. All articles of any great length should be laid perfectly level, and be evenly supported, with sufficient space to allow for expansion. This is easily accom-

plished by the form of cradle or frame used. This consists (Figs. 11 and 12) of a framework of wrought-iron bars. Loose T-irons, bent at the ends, so as to hang over the horizontal bars of the frame, are fixed in any position suitable for supporting uniformly and level, the articles to be treated; the treating-table is drawn in and out of the muffle by means of a crab-winch.

When ornamental, or other castings of great delicacy of form are treated, a sheet-iron cooling cover (*m*, Fig. 6) is lowered to receive the table as it is withdrawn from the muffle. This allows the castings, &c., to be very slowly cooled; but generally this cooling cover is not required, as the accumulated heat of the carriage and frame rarefies the air and prevents the castings from becoming cooled too rapidly. After the articles to be treated are properly arranged on the table, the chain from the winch is attached to a portable handle, which is dropped into holes in the table; the muffle doors are then lifted, and the table is slowly and carefully drawn into the muffle. The doors are next lowered, and with a trowel the attendant lutes their edges with a mixture of loam and sand. Just before the articles are drawn into the muffle the steam is gradually turned through the superheater into the muffle. A pressure varying between one atmosphere and two atmospheres is all that is necessary, as great pressure only forces the steam too rapidly through the superheater. What is necessary, before the articles are placed in the muffle, is that a plenum of steam should be established, in order to prevent the influx of air into the muffle; the heat of combustion is then turned fully over it, and by withdrawing the damper *o* (Figs. 8 and 9), is afterwards directed on to the superheater, where it is compelled to pass under and over the latter by baffler walls. These also support the floor of the muffle, and act as accumulators of heat. After passing around the superheater the products of combustion may be directed into a steam-generator. In the works of the Bower-Barff Rustless Iron Company at Southwark, it is intended that the waste heat shall, on it way to the chimney, be directed through the tubes of one of Cochrane's patent vertical multitubular boilers—a form of steam-generator very suitable for this purpose. After the temperature of oxidation is attained in the muffle, the flow of combustion is almost entirely directed immediately on to the superheater, by withdrawing the damper *h* (Figs. 8 and 9); only as much heat being allowed to pass round the muffle as will maintain the temperature of oxidation; the temperature of the muffle can be ascertained either by using a pyrometer, or visually, by withdrawing one of the movable sight-plugs provided in the doors. If the

articles are covered with rust before they are treated, the rust must be reduced, immediately the temperature of oxidation is attained, by first shutting off the steam from the muffle, and turning into it instead carbonmonoxide gas from the producers, by means of the valve *p* (Fig. 9) and its connections. During this process a good pressure of C_1O gas must be maintained, otherwise there is a danger of the ingress of air into the muffle. After the process of deoxidation, which varies in time according to the extent of the rustiness of the article, the steam must be turned on carefully.

Another deoxidizing process is occasionally used, with very good results. The method is as follows: Oil is poured into a funnel, having a siphon bend, from which it passes into the muffle by a ½-inch gas-pipe. In its passage through the latter the oil becomes decomposed and volatilized, and the hydro-carbon vapours, being prevented from escaping by the liquid seal of the oil siphon bend, are driven into the muffle, where they effectually convert the red rust Fe_2O_3 into the magnetic oxide Fe_3O_4.

It is important, in order to prevent the possibility of the influx of air into the muffle, that a continuous and uniform pressure of steam should be maintained. The least admission of air will produce an imperfect and unstable coating of magnetic oxide. Generally when air obtains ingress into the muffle, the articles are found to be covered with a film of oxide of a brilliant red colour and having a lustrous appearance. When this occurs the furnace should be at once examined, as it is a clear proof that air gets into the muffle somewhere. Occasionally there may be a leakage, and air may enter in such small quantities as not to exhibit the phenomenon described, and such has been the case with one of the furnaces at St. Neots. The magnetic oxide coating, although apparently perfect, was, after a few times' exposure to oxidizing influences, found to exhibit incipient signs of red oxidation. On examination the muffle was found to have a fractured plate. In an externally heated muffle, like that of the Barff furnace, it is possible to regulate the temperature to a nicety, a feature of great importance, when intricate and delicate articles of steel or wrought iron require oxidizing; but for heavy cast-iron articles external heating is very disadvantageous, both from the question of economy in the use of fuel, and in the time required to heat the articles up to the temperature of oxidation. Hence the advantage for cast iron of the internal and direct heating features possessed by the Bower process. Another great advantage of the latter process is that the progress of oxidation can be readily and almost

closely examined during one of the oxidizing operations. Through one of the sight-plugs in the muffler-door a lighted gas-rod is inserted, and by looking through one of the other adjacent sight-plugs, the exact character and progress of the oxidation can be clearly seen; hence the process is exactly reliable, and there need be no sense of uncertainty as to results. By the Bower process a most effective coating of magnetic oxide can be obtained in from three to eight hours, according to the thickness, character, and size of the articles to be operated upon. In this process the rustier the articles are, the more effective and speedy is the process of oxidation. Old cast-iron water- and gas-pipes, that were so covered with rust as to be commercially valueless, have been converted into a condition more durable and valuable than they were when first withdrawn from the moulder's sand. The magnetic oxide coating produced by the Bower furnace, on the surface of the roughest castings, is smooth to the touch, and has almost the finished appearance of enamel. The smoothness of the surface is, however, more apparent than real, as by microscopical examination the surface presents a granular appearance. If occasionally the articles are slightly warped, they can, by a judicious reheating, accompanied by the application of pressure, produced by weights, &c., be brought back to their original shape. A French chemist, Mr. Dodé, discovered, some years ago, a singularly cheap and beautiful process for depositing from their salts the noble metals upon the surface of a special description of enamel, which was fused upon the surface of iron and steel articles; but it was discovered that corrosion unfortunately set up under the coating of enamel, and eventually threw it off. It was decided to try Mr. Dodé's process upon the magnetic oxide coating as produced by the Bower process, and the experiments proved a decided success. The Société Française d'Inoxydation et de Platinage, though proprietors of Mr. Dodé's patent, also purchased the continental patents of Mr. Bower, and eventually those of Mr. Barff as well. By a special arrangement of the furnaces, Mr. Roque, the engineer of the Société Française, is able to treat articles of a very considerable length.

The colour of the magnetic oxide coating, as it emerges from the furnace, is a light tint of French grey, which can be made to have a silvery lustrous appearance by merely filling the muffle with the vapours of volatilized liquid hydro-carbon, produced from oil poured into a special siphon formed as already described. The colour of French grey will be retained by the magnetic oxide as long as it is free from contact with liquid grease, oil, or other hydro-carbons. The least touch of any of these instantly converts

the light French grey colour into one of a bluish black appearance, which no energy of washing or rubbing will remove. But of course the grease or oil is volatilized on exposure to heat, leaving the oxide with its original colour. All articles that are likely to be handled should be oiled. Mineral oil is the most suitable; and as the coating of magnetic oxide rapidly absorbs the oil, the least application is sufficient; and after the superfluous oil has been thoroughly rubbed off, the oxide presents a dark and polished appearance, which to some people is preferable to the delicate natural colour of the oxide.

A very pretty effect may be obtained, upon ornamental castings, by oiling the minor or subordinate parts of the ornament, leaving the prominent or main parts untouched. In the preliminary experiments with the magnetic oxide, it was noticed, that if any foreign metal was rubbed upon its surface, part of the latter was deposited or left on the former, a property not possessed, as far as the Author knows, by any other oxide; this remarkable discovery led Mr. Bower to make a series of experiments with various descriptions of metallic brushes with wires of all the noble metals, as well as of various alloys; in all cases the results were the same, and oxidized castings can be gilded, platinized, or bronzed, &c., most charmingly, cheaply and quickly, by merely rubbing over the surface of the magnetic oxide coating with metallic brushes, with bristles of any description of metallic wire other than iron. In order to permanently fix the gilt, the gilded castings are exposed to very moderate temperature, say 600° Fahrenheit, for about thirty minutes.

As already mentioned, the Société Française d' Inoxydation et de Platinage utilizes the magnetic coating as a base for receiving their special enamel. Upon this enamel, or even direct upon the magnetic oxide coating, gold, silver, platinum, &c., can be permanently deposited by mixing the chlorides of these metals with certain essential oils, and then placing the iron articles, washed with the metallic chlorides, in the furnace for a short time.

The novel feature of both the attrition and Mr. Dodé's principle of gilding, platinizing, &c., is that the same iron article can be ornamented with various metals, in conjunction, if desired, with other coatings, such as variously coloured enamels. When the oxidized castings require to be enamelled, no costly preliminary process of annealing is necessary, and the enamel can be deposited direct upon the coating of magnetic oxide.

That the strength of constructional ironwork is practically unaltered by the Bower-Barff process, will be seen by the subjoined

table of tests made by Sir Joseph Whitworth, and considered by him to be "very satisfactory." Metal tested before and after being subjected to Professor Barff's process:—

No. of METAL, 433.

Before.		After.	
Pressure in Tons.	Alteration.	Pressure in Tons.	Alteration.
Per square inch.	Inch.	Per square inch.	Inch.
18	Nil	18	Nil
19	"	19	"
20	"	20	"
21	0·0002	21	0·0007
22	0·0009	22	0·0023

No. of METAL, 603.

Before.		After.	
Pressure in Tons.	Alteration.	Pressure in Tons.	Alteration.
Per square inch.	Inch.	Per square inch.	Inch.
18	Nil	18	Nil
19	"	19	"
20	"	20	"
21	0·0002	21	0·0007
22	0·0009	22	0·0023

The following may be taken as a fairly accurate list of the thicknesses of the magnetic oxide-coatings required for various descriptions of iron:—

	Inch.
Light sheet iron, a thickness of	0·0035
" wrought " "	0·0104
Heavy " " (such as tubes), a thickness of	0·0188
Light cast " " "	0·0183
Heavy " " " "	0·0200

As the magnetic oxide is not very pliable, it is not suited for articles which have to be bent after their treatment, and if struck very violently with another hard metallic body, it is liable to chip off at the point of contact; but when the process is properly accomplished, the oxide-coating will withstand all ordinary concussions. If a piece of the oxide-coating is, however, removed, the corrosion which may set up in the denuded portion will be strictly local, and will not burrow under the coating remaining intact.

If the magnetic oxide is perfectly formed, it will resist all ordinary corrosive influences; but it is affected by contact with strong corrosive acids, although a piece of oxidized cast iron has been found to resist for a considerable period the action of dilute acids, such as urine; but the Author would not advise its adoption for apparatus used in the chemical industries, except in the laboratory, where it has been utilized with success for preserving iron tripods, Florence flask-holders, &c.

Fe_3O_4 represent the chemical equivalents forming magnetic oxide, hence the relative equivalent weights will be as follow:—

3 (56) = 168 or 72·41 per cent. Fe.

4 (16) = 64 or 27·59 per cent. O.

It is magnetic, as its name implies, and has a specific gravity of from 4·98 to 5·20.

To test the character of the magnetic oxide-coating, the oxidized articles are placed upon a damp soil, say for two hours, and are then allowed to become dry in the open air. These alternate processes of exposing the oxidized articles to wet and dry periods, are continued for several days, and if the coating is imperfect, a few days' exposure to the test described will bring its imperfections to light. If the oxide-coating resists satisfactorily the test experiment for a period of five or six days, it is perfect and durable.

One of the greatest advantages possessed by the Bower-Barff process is the completeness with which the oxidation is effected upon every part, however intricate it may be, of the metallic surface of the articles submitted to it; hence its applicability to hollow cylinders, pipes, &c., of intricate shape. Owing to the increased size of the articles submitted to the process, by the addition of solid oxygen, it is necessary that all parts which have to be fitted together, such as screws, bolts, &c., should be slightly run down or otherwise decreased in size, to allow for this addition.

The magnetic oxide-coating, giving as it does a finished appearance and smoothness to the iron, the latter can be painted, if desired, far more easily than if it was unoxidized, and the painted surface will be far more durable.

Ordinary oil-paint, when applied to unoxidized iron, has only a comparatively short life, arising from the fact that the moisture of the condensed aqueous vapour on its surface eventually permeates through the paint, setting up corrosive action, which ultimately throws it off; hence the importance of having iron articles oxidized

or Bower-Barffed, even if it is desired that they should be painted as well.

It will no doubt be obvious that the cost of oxidizing by the Bower or Barff process—or, to use a more abbreviated expression, the cost of Bower-Barffing—varies considerably; for example, one thousand small articles may be treated at the same time, and in the same cubical space, that might be occupied by a single large article; but when the latter is hollow, and when possible, the hollow space may be filled up with smaller articles.

Mr. Flamache, engineer for the Belgian State railways, who was sent over by the Belgian Works Department to report on the process, found the cost, exclusive of royalty, to be as follows: 7½ francs per 1,000 kilograms by weight, or ¾ of a centime per kilogram; and superficially, ⅜ of a centime per decimetre cube.

In the Bower furnace of the Société Française at Grenelle, the weight of objects treated in twenty-four hours varies from 47 to 85 cwt., with an expenditure of fuel of from 10 to 12 cwt. of good slack coal. In the Barff furnace, of the same form, the weight of objects that can be treated in twenty-four hours varies from 47 to 106 cwt., with an expenditure of fuel of from 15½ to 17½ cwt.

For a Barff furnace, having a muffle capacity equal to 124 cubic feet, the quantity of water evaporated per hour to supply the muffle with superheated steam, is equal to from 8 to 10 gallons. One attendant is required for every two furnaces in ordinary working; but auxiliary labour is required when loading or unloading.

The following is a list, necessarily limited, of articles, especially adapted for receiving the coating of magnetic oxide:—

Cast Iron.—Architectural ironwork; horticultural ironwork; sanitary appliances; engineering ironwork, such as water-mains, gas-mains, roof and bridge castings, &c.

Wrought and Sheet Iron; Untempered Steel.—Water-, gas-, and pneumatic-tubes; cramps, roofing-tiles, and generally all ironwork which will not be liable to rough usage, and not require bending or riveting after treatment.

It will probably be seen that the Bower-Barff process is applicable to those articles to which galvanizing is more or less inapplicable; and the former process therefore serves as a useful auxiliary to that well-known and excellent process of preserving iron by means of a coating of zinc.

For the Bower furnaces in New York, in place of bituminous coal, anthracite is used in the producers, in conjunction with gas from petroleum oil. The latter is allowed to trickle slowly through

the coal-charging hopper of the central producer, where, falling upon the anthracite incandescent fuel, it becomes volatilized and produces a very powerful reducing or deoxidizing gas. In order to prevent the oil from igniting and firing back, it is led by a pipe from a considerable distance. In the New York Bower furnaces, equal periods of both oxidation and deoxidation, of a duration of fifteen minutes each, are found to give very satisfactory results. In the same Bower furnaces Mr. A. S. Bower has been successful in carrying out the Barff process for heavy wrought-iron articles by the following method:—After the wrought-iron articles have been heated by direct combustion inside the muffle apparatus to the temperature of oxidation, the gas and air are shut off from the muffle; the chimney damper is closed, and steam is turned into the recuperator tubes, and in passing through them towards the muffle becomes highly heated. The steam is kept on continually until the temperature of the articles begins sensibly to decrease, when it is shut off, and the gas and air are turned on (in such relative proportions as not to affect the character of the oxide-coating), until the proper temperature is again regained; and the same operation of shutting off gas and air, &c., and turning on steam, are repeated, as often as required to effect a proper thickness of the oxide-coating.

This Paper is accompanied by several tracings, from which Plate 11 has been prepared.

(*Paper No. 1925.*)

"The Treatment of Complex Ores and Condensation of Lead Fumes."

By James Warne Chenhall, Assoc. M. Inst. C.E.

The treatment of complex ores and the condensation of lead fumes have been for many years important problems in metallurgy, and the Author wishes to premise that it is his intention to deal with the same, only so far as his own personal experience extends. Complex ores belong to that class, which, containing two or more minerals, cannot be separated by mechanical means (dressing), or by any of the ordinary smelting processes, as pursued in copper-smelting, lead-smelting, or gold and silver works.

It is well understood by those who have given attention to these processes that the presence of zinc in copper or lead ore, even to the extent of 5 to 7 per cent., interferes materially with the reduction of the same, and when present to the extent of 25 to 30 per cent. considerably deteriorates the value of the other metals contained in the ore, and in many cases prevents their profitable extraction.

In the case of copper ores, the presence of zinc makes them infusible, and depreciates the quality of the copper, necessitating additional softening operations. Zinc will not combine with the silicious gangue of the ore until oxidized, oxidation taking place very slowly, even when the conditions are otherwise most favourable; but the conditions in the reverberatory copper-smelting furnace are anything but favourable to the oxidation of the ore. Instances are known to the Author of charges of copper ore remaining in the furnaces from twelve to fifteen hours instead of five hours, the usual time for smelting, in consequence of the presence of zinc in the ore. Greater inconvenience still occurs from the presence of a large percentage of zinc in lead ores, as when the ordinary smelting processes are pursued not only are the operations impeded thereby, but there is also a considerable loss of lead through volatilization, arising from the increased length of time the lead products are exposed to the action of the furnace fires; and further, ores of this complex character are not adapted to the use of the zinc- or spelter-manufacturer, even when the percentage of zinc present is suitable for this process. From the peculiar nature of zinc-smelting, which is conducted in earthen retorts, it is of essential importance there should be no element

present which would readily destroy the retorts. Now the presence of lead in zinc ore is most objectionable, as it speedily destroys the retorts. Purely zinc ores, containing less than 30 per cent. of zinc, are considered valueless in this country, although ores of much lower percentage are worked on the Continent, where labour is cheap; hence the necessity of resorting to some method of separating the zinc from the other metals before the ordinary smelting processes are pursued. The mechanical method of "dressing" is, however, always adopted whenever practicable. In ordinarily mixed ores, containing galena and blende, the separation is easily accomplished by the great difference between the specific gravities of these two minerals; but in many cases separation by "dressing" is impracticable, and in others impossible; thus blende and copper pyrites resemble each other so closely in density, as not to allow of their separation by "dressing." Again, blende and galena are often so intimately mixed (forming apparently a homogeneous mineral) that their separation by "dressing" is too difficult to be practised on a large scale. The plumbiferous blende found in Anglesea, commonly known as "Bluestone," is of this character. Large quantities of copper ores are also obtainable, the working of which would be remunerative were it not for the injurious influence of zinc present in the ores, varying from 20 per cent. upwards—hitherto the highest prices paid by the copper smelters for such ores have been unremunerative to mining proprietors. The cupriferous blende found at Aïn Barbar, Algeria, is also of this class.

The following are the complete analyses of three varieties of complex ore, also the metallic contents of four others, all of which have been successfully treated by the methods hereafter described.

	Constantine.	Cavalo.	Bluestone.
	Per Cent.	Per Cent.	Per Cent.
Zinc (as sulphide)	10·64	13·40	29·28
Lead	4·81	17·14	12·90
Copper	1·35	0·44	0·65
Silver and gold	0·04	0·06	0·03
Sulphur	26·85	15·37	22·14
Iron	19·93	4·98	7·16
Alumina	2·33	1·02	..
Magnesia	..	0·22	..
Barium, sulphate	..	35·04	..
Silica	26·48	11·19	26·84
Arsenic	0·65	0·13	0·15
Lime	0·60	..	0·84
Sulphuric acid	3·53	..	..
Antimony	0·02	..	..
Oxygen and loss	2·77	1·01	1·01
	100·00	100·00	100·00

	Copper.	Zinc.	Lead.	Silver.
	Per Cent.	Per Cent.	Per Cent.	Oz. per Ton.
Rio Malagon ore .	4·5	31·65	18·25	16·75
Lead blende . . .	..	4·75	12·50	14·75
Lead calamine . .	..	27·00	29·75	18·00
American ore . .	0·2	27·20	12·00	23·20

The foregoing examples will suffice to give a clear idea of the character of the ores referred to. The extraction of the zinc from such ores has often been attempted by means of hydrochloric acid after calcination, with the view of decomposing the chloride of zinc by lime; but the serious difficulty of washing the oxide of zinc free from the chloride of calcium, and obtaining it in a form dense enough for the spelter manufacturer, and also the presence of chlorine in any form being injurious in the subsequent smelting of the residue containing lead and silver, have prevented this method of treatment being successfully followed.

In February, 1877, Mr. Edward Andrew Parnell, of Swansea, took out a patent, No. 820, for improvements in the manufacture of metallic zinc and sulphuric acid, and it has been the development of that patent which has led to the successful treatment of the ores under consideration, the gist of which consists in the dissolving of oxide of zinc from calcined ore by sulphuric acid, and the after decomposition of the sulphate of zinc by sulphide of zinc or carbon. When heated alone, sulphate of zinc requires a very high temperature to effect its decomposition. Such a method is impracticable on a large scale; but when mixed with a deoxidizing agent sufficient to take one equivalent of oxygen from the sulphate, it is easily decomposed, the product being oxide of zinc and sulphurous acid. A mixture of two equivalents of sulphate of zinc with one equivalent of carbon, heated to dull redness, affords oxide of zinc. (With a large proportion of carbon, sulphide of zinc is produced.) A like decomposition is effected by means of sulphide of zinc, whether native or artificial; but at a considerably higher temperature, three equivalents of $Zn\ SO_4$ (sulphate of zinc), and one equivalent of Zn. S (sulphide of zinc) produce four equivalents of oxide of zinc, and four equivalents of sulphurous acid ($3\ Zn.\ SO_4 + Zn.\ S = {}_4Zn.\ O + {}_4SO_2$). Native sulphide (zinc blende) is the reducing agent preferred on the large scale for making oxide of zinc suitable for the manufacture of zinc or spelter.

In the treatment of the ores already described, it is found expedient to divide them into two classes, viz., those in the first class, which contain zinc in sufficiently large quantities for its extraction by Mr. Parnell's process, which should be from 15 to

35 per cent. of zinc; and those of the second class, which vary from 5 to 15 per cent. of zinc. It is proposed here to deal first with the classes of ores rich in zinc, and the poorer ones afterwards. The mode of treatment for the ores rich in zinc is, in the first place, to grind it sufficiently fine to pass through a sieve of six or eight holes to the lineal inch. This is accomplished by passing the large lumps of ore through a Blake's stone-breaker, and from thence through a Cornish crushing-mill, having two series of rolls, the upper ones being fluted on their faces, and the lower ones plain (Plate 12, Fig. 1.) The only point in this mill calling for special remark is the introduction of india-rubber buffers instead of springs or levers, to allow the opening of the rolls during the passage through of the material, and to give the necessary pressure for crushing.

The next stage is to calcine the ground ore by exposure to air at a moderate heat. This is effected in muffled furnaces, 46 feet in length by 15 feet in width, outside measurement. The furnace is so constructed that the heated gases from the fireplace pass along above the muffled arch, and then descend at the opposite end of the furnace, traversing the flues under the working bed twice, before their exit to the chimney-flue; thus the products of combustion travel a distance of about 120 feet before escaping to the chimney (Plate 12, Fig. 2). There is no difficulty in keeping this furnace at a uniform heat throughout its whole length, with the consumption of about 13 to 14 tons of coal per week. It is of the utmost importance that the operation should be conducted at a moderate temperature, to allow as much of the sulphide of zinc as possible to be transformed into sulphate of zinc, in order to reduce the consumption of sulphuric acid, in its after treatment; and further, if the ore be calcined at a very high temperature, the zinc is not so readily dissolved out; silicate of zinc and silicate of lead being formed produce a gelatinous silicate, which impedes the after-washing of the ore and delays the settling of the fine ore in suspension.

The next operation consists in the dissolving of soluble sulphates of zinc, and oxide of zinc by sulphuric acid and water, and is conducted in large rotatory pans, designed by the Author for the purpose. Their diameter is 10 feet, depth 2 feet, and they are made of cast iron, lined with sheet-lead $\frac{3}{8}$-inch thick, so as to prevent the action of the acid upon the pan. These pans are revolved by spur-gear, fixed on the top of massive frames, between which they are placed. There is also a cross-bar over each pan, to which is attached a number of ploughs or scrapers, so that when the pans

are turned round the ore is thoroughly mixed with the liquor (Plate 12, Fig. 3.) The mode of conducting this operation is as follows:—Acid liquors, partially saturated from previous working, are run into the pans, to which is added a sufficient quantity of calcined ore to neutralize the whole of the acid present in the liquor. By this means a liquor is obtained of about 40° Twaddle, or containing about 14 lbs. of dry sulphate of zinc per cubic foot. This operation is repeated until about 4 tons of ore have been put into each pan. Each instalment of neutralized liquor being run off into suitable vessels. The ore in the pans now receives an excess of sulphuric acid to dissolve out the remaining oxide of zinc, and is then further washed with water. These water-washings, and the previous strong acid liquor, are run into suitable tanks, and are, in fact, the partially saturated liquors before referred to as being neutralized in the first operation in the pans. The liquors from this process are allowed to traverse long shallow settling troughs before entering the tanks for the final settlement of all suspended particles of ore. In the method just described the principal part of the zinc in the ore is dissolved, and about two-thirds of the copper, but very little of the iron, provided it has been thoroughly oxidized during calcination.

The residues remaining in the revolving pans after the extraction of the zinc, and those that are arrested in the settling shoots and tanks, contain the whole of the lead and silver, and about one-third of the copper in the original ore as delivered to the calciners. In some cases it has been found that the fine particles of ore separate very slowly from the liquors in the settling tanks, and separation is further impeded when a gelatinous silica is present; but in the latter case only is recourse had to mechanical filters to surmount the difficulty. The clear liquors containing zinc and copper are now run into suitable tanks, in which the copper is precipitated in the ordinary manner, pursued in the various humid processes for the treatment of copper. The reagent generally used is scrap iron, the oxide of iron produced having very little injurious effect upon the retorts in which zinc smelting is conducted. Metallic zinc and sulphuretted hydrogen are both suitable for this operation, but the former is the cheapest.

The copper precipitate obtained is thoroughly washed with water to free it from sulphate of zinc, and from small pieces of undissolved metallic iron. It is then dried and smelted by the usual copper-smelting process.

The zinc-liquor is now conveyed into long evaporating furnaces,

in which the heat is applied over the surface, and the evaporation continued until it reaches the strength of 90° Twaddle, or a density of 31 lbs. of sulphate of zinc to the cubic foot. It is then run into furnaces of smaller dimensions (Plate 12, Fig. 4), provided with two cast-iron lips, and fitted with doors to admit of the dry sulphate being removed. The heat in these furnaces is also applied over the surface of the liquor, and the evaporation continued until the sulphate of zinc becomes of the consistency of ordinary mortar. When the evaporation has reached this point, the determined quantity of very finely ground sulphide of zinc (blende) is added, and thoroughly mixed with the semi-dried sulphate. The blende is ground fine enough to pass through a screen having thirty holes to the lineal inch. As soon as the mixing of the blende is effected, the drying of the sulphate mixture is continued in the same furnace, until it has become thick enough to be easily removed. It is then spread, whilst hot, upon suitable floors, so as to harden thoroughly previous to being operated upon further. It may appear an extravagant mode of evaporating, and this the Author admits; but it is the simplest and most expeditious method yet introduced to overcome the difficulty in connection with this material. These liquors when boiling act very perceptibly upon either wrought or cast iron, and, in fact, upon any metal other than lead, thus precluding their use. The result of numerous experiments has also disclosed the fact that, if the heat be applied to the bottom of these furnaces instead of over the surface of the liquors, the speedy destruction of the bottoms of the furnaces ensues, arising from the immediate adhesion and instantaneous hardening of the sulphate of zinc.

The next operation is to deal with the dried sulphate of zinc in the production of oxide of zinc, and the formation of sulphurous acid. This operation is carried on in muffled furnaces, each having four distinct compartments, and each compartment being capable of holding a charge of about 2 tons of the sulphate of zinc mixture. These furnaces are about 30 feet long, and 16 feet wide external measurement (Plate 12, Fig. 5). Their construction, as regards the application of heat, is, in every particular, similar to the calcining furnaces already described. The furnaces having been charged and the moisture driven off, the doors are closed and sealed with clay, and remain so for about twenty-six to twenty-eight hours. The sulphate of zinc during this time is thoroughly decomposed, producing oxide of zinc and sulphurous acid, and the sulphurous acid is conveyed by suitable flues to lead chambers for the manufacture of sulphuric acid in the usual way. In practice

it is customary to use an excess of the deoxidizing agent, and therefore it is necessary that the remaining undecomposed sulphide of zinc should be oxidized by calcination. This is effected in the same furnace by stirring the charge through the doors. The object of dividing the furnace into compartments is to reduce the loss of heat to a minimum, also to secure a saving in time in the furnace regaining its maximum temperature. It is obvious that the other three-fourths of the furnace will radiate heat to the cool portion, whereas a whole furnace being charged simultaneously, the cooling is found to be so extensive as to take a longer time to attain its maximum temperature than to complete the operation. The division of the furnaces also affords better control over the charges. The oxide of zinc produced is now ready for treatment in the ordinary zinc-smelting process.

Having thus dealt with the liquid portion from the washing operations, the treatment of the residues therefrom, together with the poorer classes of ore, will now be considered. The former contain a large percentage of lead and a little copper, and the latter contain a high percentage of copper and very little lead. The lead-residues are mixed with the fumes obtained from the smelting operations, and agglomerated in suitable reverberatory furnaces. Both classes of ore, and the residues described above, are then smelted in small blast furnaces, the ore in its normal condition, and the lead-residue after agglomeration. The charging-hole of the Cupola furnace for the lead material is from 7 feet 6 inches to 9 feet above the blast twyers, and the charging hole for the copper material is from 2 feet 6 inches to 3 feet 6 inches above the twyers. It may be here mentioned that the latter description of furnace is used by the Swansea Zinc-Ore Company, Limited, but with the addition of hot-air stoves attached to the throats of the furnace, thereby obtaining a hot blast for smelting, which has proved of very considerable help in the case of refractory ores. The agglomerated material produces argentiferous pig lead, and a small quantity of copper regulus, the latter resulting from the undissolved copper remaining in the humid process residues. The copper material when smelted produces argentiferous regulus, which is desilverized in the following manner:—The copper in the regulus is concentrated to about 45 per cent., then finely ground and thoroughly oxidized by calcination, and afterwards dissolved out by sulphuric acid. The resultant residues are then smelted with lead products, forming argentiferous pig-lead, and the pig-lead is desilverized by the process pursued in ordinary lead-smelting works.

Another element in the treatment of complex ores is the arresting of the fumes produced in the blast-furnaces already alluded to, and is effected by the method introduced by Messrs. Wilson and French in 1878. The process consists of the exhausting of the products of combustion, together with the fume containing lead and zinc from the top of the blast-furnaces, and the forcing of them through a depth of from 4 inches to 9 inches of water, under which is arranged a series of wooden frames covered with metallic gauze. In case of the liquors acting upon the metallic gauze, wickerwork basket-frames are substituted. Another point of essential importance in this system of condensation, is the disintegration of the fume contained in the smoke under water, by which the metallic particles are instantly wetted and sink to the bottom of the condenser. The machinery employed for this operation is a specially designed Root's Blower, manufactured by Messrs. Thwaites Brothers, Bradford. There are two of these machines at the Swansea Complex-Ore Company's (Limited) Works, each of which is capable of passing 30,000 cubic feet of gas per minute, say, at 300° Fahrenheit, against a pressure of 12 inches of water. The cooling of the gases from the furnaces prior to entering the exhauster is effected by allowing them to pass over a series of open pans, one above the other, filled with water. No difficulty is experienced in keeping the gases sufficiently cool to avoid fire in the wood condenser (Plate 12, Fig. 6), or injury to the machinery. The fumes obtained are then washed with sulphuric acid, to separate the zinc from the lead. The lead fumes go to the agglomerating furnace with the lead residue, and the liquor containing zinc to the department first described.

The Paper is accompanied by six sheets of tracings, the figures on which have been reduced and engraved on Plate 12.

APPENDIX.

LEAD and SILVER PRODUCE from SMELTING 1,269 tons 9 cwt. of DRY ORE in COLD-BLAST FURNACES, at the SWANSEA ZINC-ORE CO.'s (LIMITED) WORKS, LLANSAMLET, SOUTH WALES, DURING THIRTEEN WEEKS.

Week Ending	Total Quantity.					
	Ore Smelted.	Lead Contained in the Ore.	Silver and Gold in the Ore.	Lead Sold as Pig-Lead.	Silver Sold.	Gold Sold.
	Tons cwt.	Tons cwt. qrs. lbs.	Oz.	Tons cwt. qrs. lbs.	Oz.	Dwts.
1880						
Dec. 22	101 14	6 2 0 4	1,159	5 9 2 2	1,149	211
„ 29	44 13	1 19 2 15	308	4 4 1 23	1,082	215
1881						
Jan. 5	109 1	4 12 2 26	817	2 13 1 11	389	
„ 12	119 11	5 13 0 5	850	6 12 2 0	852	54
„ 19	104 10	8 1 3 25	783	3 17 3 0	697	95
„ 26	114 4	6 9 0 4	1,056	2 18 3 4	524	36
Feb. 2	117 0	11 5 0 25	1,029	4 17 0 14	687	117
„ 9	118 7	8 2 3 1	1,112	3 12 3 27	671	132
„ 16	108 13	3 1 3 27	937	4 8 2 5	1,003	258
„ 23	57 10	3 13 3 0	618	3 2 1 17	837	245
March 2	126 12	3 5 2 18	1,037	3 2 3 6	948	288
„ 9	84 1	2 4 2 20	836	1 18 1 20	850	186
„ 16	63 3	2 2 1 21	704	5 14 0 7	1,169	244
	1,269 9	66 14 3 23	11,246	52 12 2 24	10,858	2,081

In addition to the above 200 tons of copper regulus were sold, having part of the silver and gold therein, with an average of 6 per cent. of lead, which is equal to 12 tons.

	Tons cwt. qrs. lbs.
Total lead in the ore	66 14 3 23
Total lead sold as pig lead	52 12 2 24
„ „ „ in regulus	12 0 0 0
„ loss of lead	2 2 0 27
	66 14 3 23

	Oz.
Silver and gold in the ore	11,246
Total silver sold	10,858
„ gold sold	104
Loss	284
Total	11,246

(*Paper No. 1938.*)

"Water-Supply and Irrigation of the Canterbury Plains, New Zealand."

By George Frederick Ritso, Assoc. M. Inst. C.E.

The Canterbury Plains, on the east coast of the Middle, or South Island of New Zealand, comprise an area of about 2,500 square miles, stretching along the seaboard from the river Ashley to Banks' Peninsula, and below Banks' Peninsula from Lake Ellesmere to the Rangitata river, a total distance of about 90 miles. They extend inland, for distances varying from 25 to 40 miles, to the foot of the spurs of the mountain ranges, which form the backbone or dividing range of the country. At the foot of the ranges the elevation of the country is about 1,500 feet above the sea, and from this height the plains slope gradually down to sea-level at the coast. These plains (Plate 13, Fig. 1) are intersected by six principal rivers, which rise in the mountains, and flow eastwards to the sea. They are the Waimakariri, Selwyn, Rakaia, Ashburton, Hinds, and Rangitata. They are all of a similar character, running over shingle beds, consisting of rounded boulders, and they are none of them navigable (except the Waimakariri to Kaiapoi, about 2 miles inland), as they flow rapidly over shallow shifting beds, in some places more than a mile in width. They are subject at times to very heavy floods, and are frequently very low in autumn, becoming small streams in a wide dry bed of shingle; and in droughts, they frequently disappear in portions, and flow beneath the surface of the shingle.

The soil of the greater part of the plains is alluvial from about 6 to 8 inches deep, resting on an immense deposit of shingle, which varies slightly in character from being mixed with clay to pure washed shingle and sand. This soil before cultivation nourishes a grass which grows in bunches or tussocks. The whole of this large area is treeless except in some small portions, where an occasional cabbage-palm grows, and the dry north-west winds, robbed of their moisture in crossing the mountain ranges, sweep over its unsheltered surface.

The fall of the plains from the foot of the mountains to the sea forms a tolerably regular parabolic curve, the gradient at its

steepest being about 80 feet to the mile near the hills, and gradually diminishing as it approaches the seaboard. The river beds form a similar curve, with a less slope at the upper portions, where they rise in rocky gorges in the mountains, and on emerging on the plains generally run between high terraces, in deep beds worn in the shingle. The boulders composing their beds are large and coarse near the hills, and become regularly more rounded and smaller as they travel towards the sea. The general slope of the plains is in a south-easterly direction, but the regularity of the fall is disturbed by occasional small terraces and shallow gullies. They were formerly subject occasionally to heavy floods from rain or sudden melting of snow. But the greater part of the plains being now taken up in farms of from 100 to 1,000 acres or more, and cultivation beginning to spread over them, the effects of fencing, ploughing, ditching, and roadmaking has been to diminish the force of these periodical floods. Moreover overflows from the streams are now prevented by banks, &c.

Near the hills water is obtainable in wells at a moderate depth, and also near the sea, but there is a stretch of country, about 20 miles in width, where no water can be obtained (except from the rivers) at a less depth than 200 feet below the surface. Before cultivation was introduced the plains were occupied as sheep-runs, and the merinos, in the proportion of one sheep to 5 or 6 acres, managed to exist without a regular water-supply on the scanty tussock grass, aided by the occasional heavy dews. The process of changing the plain lands into farms, consists, simply of fencing with sod-banks topped with stakes and wires, breaking up the land with the plough, and taking a crop of wheat, followed next season by a crop of oats, and then laying down the land to pasture in English grasses. As soon as the farmer arrives at that stage, the want of water is felt very severely for cattle and half-bred sheep, which cannot, like the hardy merinos, do without it. An occasional windmill-pump has been erected by one or two of the more enterprising farmers to draw water from depths of from 200 to 300 feet, and the roofs of farm-buildings have afforded a scanty supply, which has had to be supplemented by carting water from the nearest river in tanks on wheels. Even the cartage of the small quantity of water required for farm-horses costs, in some instances, £20 per annum for a 300-acre farm.

Malvern Water-Supply.

The question of irrigating the plains, or at least of providing a supply of water for farm-purposes and watering stock, engaged the attention of the late Provincial Government of Canterbury as far back as 1870, and a sum of £25,000 of public money was allocated to be spent in a water-supply for the portion of the plains between the Waimakariri and the Selwyn rivers, to the westward of Christchurch, known as the Malvern district. Levels were taken, partial surveys made, and a point, about 40 miles inland on the river Kowaï, a tributary of the Waimakariri, was selected as the most suitable place for the construction of headworks. The greater part of the plains were then Crown lands in the possession of the Government, though open for purchase to the public at £2 per acre. The greatest difficulty to contend with was the excessive fall of the plains, at their commencement, at the foot of the hills. It was thought a direct channel carrying a large quantity of water would be destroyed by the scouring away of the light soil, and that the water would be lost in the porous shingle. Several schemes were devised to overcome the difficulty; one being that of a serpentine channel having a fall of 8 feet per mile, with rapids at the bends of the channel; and the lands were partially surveyed with the view of carrying this plan out. Another scheme was that of lining the channel with sods. Another proposal was for a concrete-lined trench; and another to bring down the water in earthenware pipes. All these schemes were objected to.

In 1875 the Provincial Government let a contract for £14,500 for the construction of headworks at the river Kowaï. The works consist of a concrete dam 300 feet long across the river, between two convenient points of rock, going down through the shingle, and 2 feet into the bed rock of the river, so as to intercept all the water flowing through the shingle. The dam is 3 feet in width on the crest, with a trough in front to protect the foot of it from being scoured by floods, and it is provided with scouring sluices to keep the channel in front of the sluice-chamber clear of shingle. The sluice-chamber leads into a tunnel lined with brickwork 1,012 yards long, which conducts the water into an open channel about 1½ mile in length, 14 feet wide, and 2 feet in depth. The channel is protected from scouring by concrete falls, dropping 6 inches at each fall, the gradient of the country being 80 feet per mile. This channel discharges into a small creek-bed which was

usually dry about ten months in the year. Before the works were advanced so far, however, the Provincial Governments of New Zealand were abolished, and the General Government took them over. The works, as above described, were completed by the General Government, and then handed over to the Selwyn County Council, they being situated in the newly created "County of Selwyn."

The capacity of discharge of these works is estimated to be equal to 28,800,000 gallons per diem, the tunnel being 5 feet 6 inches high and 3 feet 6 inches wide, with a fall of 12 feet in its length. These works were, however, comparatively useless for the purpose of irrigation or water-supply to the plains below, as the water was merely carried by the creek above mentioned to the river Hawkins, a small stream about 5 miles below, where it was speedily lost in the shingle.

These works, and an unexpected balance of about £8,000, having been handed over to the Selwyn County Council, a further length of about 2 miles of water-race was constructed by that body, tapping the small creek about 5 miles below the place where the channel discharges into it, and in a straight line down the fall of the country towards Sheffield. The channel was excavated much deeper than the one above, the average fall being about 60 feet per mile; sixty-five timber falls of 2-feet fall each were put in to maintain the channel (Plate 13, Figs. 2, 3, 4).

A heavy flood, in July 1878, broke in at the head of this last constructed channel, just as the works were completed, and swept it from end to end, washing out every fall but two, and reducing the bottom of the channel to a uniform slope of shingle. After this occurrence strong sluice-gates were erected at the juncture of the creek and water-race, and concrete falls were constructed in place of the timber ones, when the channel silted up and became watertight.

In 1879 a further portion of the main channel, about 2½ miles in length, was constructed with concrete falls 1 foot in depth, and passing under the roads and railway by concrete-culverts. These works conducted the water as far as Waddington, about 12 miles below the head-works. Up to this point the cost was unusually heavy, owing to the numerous road-crossings and a culvert, 264 yards long, at the Sheffield Railway Station, and also to the fact that concrete-falls were used, averaging £5 each in cost. The channel below this was divided into two branch races, each 8 feet in width, with timber-falls of 6 inches drop each. These branches were continued down the plains, in a direct line for a distance of about 15 miles. In July 1881 a heavy flood occurred just after

their completion, which tested the works severely, the whole of the falls being submerged; but they stood the action of the water without injury, as the shallow banks of the channel acted as waste-weirs, and let the water in and out again without doing any damage.

The fact that the funds for these works were very limited, and the necessity for carrying the water as far as possible, led to the method of construction adopted in these branch races, viz., that of letting contracts, in lengths of about 4 miles each, for ploughing and scooping a rough channel, 7 feet wide at the bottom and 1 foot deep, with side slopes of 1 to 1, the spoil being disposed neatly on each side in banks. These contracts were let to, and carried out by, the settlers, and there being no spade-work, the prices averaged about £20 per mile. Level-pegs were then fixed down the channels, having their tops 3 inches above the bottom, with a drop of 6 inches at each peg, their distances apart of course varying with the fall of the ground, which ranged from 45 feet down to 20 feet per mile. The construction of timber falls to the levels of these pegs was then let in convenient sections, at an average schedule price of 18*s.* per fall. There are about two thousand three hundred falls in the branch races. Where these branches cross well-defined gullies or floodwater courses, timber flumes are fixed, to carry the flood-waters over the races. The correctness of the theoretical action of the timber falls has been proved by the shape which the bottoms of the channels have assumed in a few months, after the action of the water has had time to scour the channel and deposit silt. Where the channels cross public roads, small timber bridges on concrete walls were erected, costing about £30 each. The average cost of these branch water-races was about £100 per mile, including all works connected with them.

At the ends of the main branches, the slope of the plains having diminished to about 20 feet per mile, and the quantity of water to be conveyed being much less, the channels were divided into a number of small branches without falls, being simply ploughed and scooped channels, about 3 feet wide and 8 inches deep, excavated at the sides of the road reserves. These reserves were laid off of a width of 1 chain of 66 feet, and the roads having been formed only 50 feet wide, a breadth of 16 feet was left available for water-channels. About 33 miles length of small channels were made, at an average cost of about £8 per mile. They have carried the water up to the present time without scouring, except in a few places where the fall of the ground exceeds the average,

and small falls will ultimately have to be put in at these places to prevent the destruction of the channel.

Distribution of the Water.

During the progress of these works, the whole of the land previously unsold was alienated from the Crown, and the greater portion was fenced and cultivated. Nearly all the roads in the Malvern district had been formed, and the settlers began carting water from the races to their farms. Although the water-races were a considerable boon to the district, and diminished greatly the distance of cartage, the great object, that of abolishing the carting of water altogether, and of bringing it to every homestead and paddock, was not yet accomplished. The distribution of the water to all the various properties presented considerable difficulties, and the funds at the disposal of the County Council were nearly exhausted. There were no means for the construction of a proper system of secondary channels, and a large outlay would have to be incurred, even for the necessary surveys and levels for constructing a network of distribution channels.

The Selwyn County Council therefore proclaimed a water-race district, containing an area of about 118,000 acres, and including in its boundaries all lands which would benefit by the Malvern Waterworks. The district was subdivided, after deducting about 10,000 acres for roads, public reserves, &c., into seventy-two tolerably convenient blocks of, as near as possible, 1,500 acres each in area. The system under which the land had been sold greatly facilitated this, as the lands were generally surveyed in small sections, principally in rectangular blocks. Applications for water-supply were then invited from the proprietors of these blocks of land, under by-laws made by the County Council, with the provision that the necessary works should be constructed by the proprietors themselves, one supply or "head race" being given to each block of 1,500 acres. The settlers, being nearly all freeholders, this course met with their approval, and was considered preferable to burdening the district with a rate for the construction of a large number of small races by contract. It was also thought that by giving each owner the privilege of taking the water on to his property, as far as possible the proprietors would use the water for irrigation purposes, and that thus a system of irrigation would be initiated on the plains. For the full irrigation of every acre in the district, about ten times the volume of water obtainable from the river Kowaï would be required; but, under the block-

system, each proprietor is able to use the water to which he is entitled for irrigating part of his land, and the proprietors are thus, so to speak, being educated up to the benefits to be derived from irrigation, and prepared for the time when a larger system of works can be constructed.

The full volume of water flowing in the water-race being variable, and depending on the supply at the headworks, was theoretically divided into seventy-two heads, being one head for every block of 1,500 acres; and a system of gauging had to be adopted, which would deliver to each block, as near as possible, an equal part of the water at any time flowing in the race, due allowance being made for evaporation and percolation.

The gauging into the small head-races, which conduct the water into the blocks, is done by fixing a stout sheet-iron box on the crest of the most convenient fall to each block. These boxes have their openings 12 inches high, and of the uniform width of $2\frac{1}{4}$ inches, with sharpened edges, so as to diminish the friction of the water against their sides as much as possible (Plate 13, Fig. 5). The width of the falls in each of the two branch races being 8 feet, and allowing 30 inches of the 192 inches in width of crest, or a deduction of about $\frac{1}{6}$ for evaporation and percolation, the $\frac{1}{72}$ part would be $2\frac{1}{4}$ inches, which fixes the width of the gauge. After the gauges had been put in, the width of each fall on which a gauge was placed was reduced, so as to bring the water flowing through all the gauges to as uniform a height as possible. The $\frac{1}{72}$ part of the water thus passes into the small head-race, giving about 200 gallons per acre per diem, and the remaining water flows over the fall down the race. The dry north-west winds were found to have an appreciable effect in reducing the quantity of water delivered at the lower end of the races; and, considering the variable evaporation over such an extent of country, the system of equally dividing the available water can only be considered an approximate one. The percolation is small, as the constant tendency of channels with falls is to silt up, and to become more watertight.

Other Schemes of Water-Supply.

In the Ashburton County, south of the Selwyn County, a system of water-races has been carried out by ploughing and scooping channels about 3 feet wide by 9 inches deep, the supply of water being taken by headworks in several branches of the rivers at the foot of the hills.

These channels, some 4 or 5 miles apart, supply water to about 300,000 acres of land, and are said to assist scouring. The landowners are not, however, permitted to divert the water on to their properties, and many are still obliged to cart water. The supply per acre is about one-tenth that of the Malvern water-race, being about 20 gallons per diem. A similar scheme for water-supply is being initiated in the Eyreton district, north of the Waimakariri in the Ashley County; but this scheme will not permit of the water being used even partially for irrigation.

No country could be more advantageously situated for irrigation than the Canterbury plains. The rivers bring down ample supplies of water at the proper season, and the country being overspread with shingle, below a thin covering of good soil, underdraining, which is one of the great expenses of irrigating ordinary lands, is entirely unnecessary. The fairly uniform slope of the plains favours the making of proper terraces and channels for irrigation. The growing of crops is limited by the lightness of the land, and its inability to bear more than about one grain crop in four years.

The expenditure so far on the water-supply of the plains has been about £50,000 for about 500,000 acres irrigated, or, say 2*s.* per acre; but the effect has already been to raise the value of the lands at least £1 per acre, and in some places more.

No doubt, in a few years, works will be constructed for the purpose of using the waters of all the principal rivers for irrigating the plains, thus making water-meadows, which will probably fatten five or six sheep, or a proportionate number of cattle, to the acre, on land 2 acres of which will now barely support one sheep.

The Paper is accompanied by two small-scale tracings, from which Plate 13 has been engraved.

(*Paper No. 1939.*)

"Raising the S.S. 'Austral.'"

By John Standfield, M. Inst. C.E.

The "Austral" is the largest and most recently built vessel of the Orient Steam Navigation Company's line of steamers trading between London and Australia. Her dimensions are:—Length, 455 feet; breadth, 48 feet; depth in hold, 37 feet; gross registered tonnage, 5,588.

On the 11th of November, 1882, in Neutral Bay, Port Jackson, Sydney, the "Austral," after having discharged cargo, was taking in coal on the starboard side, for which purpose the lower coal-ports were wide open; the water ballast provided for ensuring stability at such times had been removed from the double bottom; as the coaling proceeded the side of the vessel gradually went lower, till some of the coal-port sills were brought under water, of which a great quantity poured into the hold. The officers and crew on board, numbering between seventy and eighty men, were asleep in their berths; only a few coal-trimmers were at work, and the dangerous state of affairs was not discovered till the vessel was fast heeling over. The alarm was immediately given by the coal-trimmers, and all but five men managed to escape. The collier put on steam and escaped from the side of the sinking vessel, breaking the mainmast in getting free; as soon as the collier was clear, the "Austral" went down stern first, at 4.30 A.M., about twenty minutes after the alarm had been given, in about 52 feet depth of water at the stern, and rather less forward, settling with a list of 11° to starboard. At the time of going down 200 tons of iron and 1,500 tons of coal were on board.

Owing to the great difficulty of handling such an enormous vessel, it was very generally thought that the ship would become a total loss; but the managers of the line, Messrs. Anderson and Anderson, determined that no effort should be spared to raise her at once. They therefore sought an interview with the Author, who objected to any system of lifting such an exceptional vessel by means of external appliances, and advised that the only safe and certain method of procedure would be by pumping out the water after having made her watertight. The first arrangement for obtaining this object was by constructing timber caissons to be lowered over

each opening in the deck, and round the saloons, engine-hatches, &c.; these caissons were to extend above the water-level and be open to the air, and to be made watertight to the decks. Each watertight compartment was to be provided with its own air-pipe and water-pipe leading to the pumps. The want of a sufficient number of skilled divers at Sydney, however, caused this arrangement to be somewhat modified, as shown in Plate 14, Figs. 1 and 2. It was finally decided to build up the sides of the vessel to above the water-level by means of timber-work, forming a continuous cofferdam.

As before mentioned, the "Austral" had a list of 11° to starboard. With this list remaining constant, it was calculated that upon reducing the water-level within the cofferdam to a depth of 10 feet, viz., from P to Q (Fig. 1), a displacement would be obtained of about 6,000 tons; also, that the horizontal distance between the centre of gravity, G, of the whole structure, and a line dropped vertically from the centre of displacement, *g*, would be about 4 feet, giving a righting moment of 24,000 foot-tons.

Mr. George Eldridge, M.I.N.A., the Company's naval architect, was sent out on the 8th of December to take charge of the work in conjunction with Mr. Yuill, Assoc. Inst. C.E., the Company's manager, resident at Sydney.

The methods adopted for the construction and fixing of the cofferdam are shown in Plate 14, Figs. 1 and 2. The cofferdam was 410 feet long, about 30 feet in depth, and was furnished with a central transverse bulkhead, so that it was divided into two watertight compartments. By this arrangement easy control was ensured over the vessel, as she could be pumped fore or aft, and could be trimmed longitudinally as desired. The vertical timber-frames of the cofferdam were placed uniformly about 8 feet apart. Every two opposite frames were connected, wherever possible, by a horizontal strut, which was in its turn supported by two small vertical struts (Fig. 1). C C are longitudinal walings tying the system of struts. When erecting the cofferdam it was decided to further strengthen the frames by sloping shores to the deck and to the masts where possible. It will be seen that the cofferdam commenced a few feet below the upper deck, and was continued for nearly the entire length of the vessel (Fig. 2). It was made on shore in complete sections, each 16 feet in length, the skin being formed of planks of Kauri pine spiked to the frames. These sections were weighted and lowered into position from derrick barges alongside, and were attached to the vessel by bolts passing through the side-lights, and secured on the inside by divers by means of toggles D and E.

When the outer skin of the cofferdam was completed, instead of being calked (which would have been a work involving great delay), it was made watertight by a covering of canvas, tacked on as shown in Fig. 1, with sufficient slack to allow of contraction; this covering extended a few feet below the bottom edge of the cofferdam, forming a flexible apron which the pressure of the water caused to closely fit to the sides of the vessel, thus making a thoroughly watertight connection immediately that the water-level inside the cofferdam was lowered by pumping. The amount of canvas covering was 26,000 square feet.

The pumping-gear consisted of one direct-acting 20-inch pump, capable of throwing 14,000 gallons per minute; two 15-inch pumps, each driven by a 12-HP. engine, and each capable of throwing 7,000 gallons per minute; four 10-inch pumps, each capable of throwing 3,000 gallons per minute; two 7-inch pumps, capable of throwing 8,000 gallons per minute; and one 9-inch pump, capable of throwing 2,000 gallons per minute. The latter were each driven by 10-HP. engines. This machinery, when in full working order, was capable of pumping 230 tons per minute, or over 13,000 tons an hour. The motive power for the pumps was supplied by six steamers alongside.

The first pump was started on Tuesday, the 27th of February, 1883, at 5.37 A.M., and the others subsequently at short intervals, the mean time for the starting of the series being 6.5 A.M. A depth of 7 feet of water was pumped out of the ship by a quarter past 7 o'clock, and the ship speedily commenced to right. Immediately the pumps were in motion the water could be seen receding.

When pumping was commenced the vessel had a list of about 11° starboard; or, in other words, the after part of the ship was about 10 feet lower on one side than on the other. At 6.50 A.M. the list had been reduced to $10\frac{7}{8}$°; at 7 A.M., to $10\frac{3}{4}$°; at 7.5 A.M., to $10\frac{1}{2}$°; at 7.8 A.M., to 9°; at 7.15 A.M., to $7\frac{1}{4}$°; at 7.17 A.M., to $6\frac{1}{2}$°; at 7.18 A.M., to 6°; at 7.22 A.M., to $5\frac{1}{2}$°; at 7.24 A.M., to 5°; at 7.28 A.M., to $4\frac{1}{2}$°; at 7.31 A.M., to $4\frac{1}{4}$°; at 7.35 A.M., to 4°; at 7.40 A.M., to $3\frac{3}{4}$°; at 7.43 A.M., to $3\frac{1}{2}$°; at 7.45 A.M., to $3\frac{1}{4}$°; at 8 o'clock to $2\frac{1}{4}$°, and at 8.30 A.M., to $1\frac{3}{4}$°. It will thus be seen that the vessel had been gradually rightening herself port and starboard, and the list had been almost reduced to a level. It will be understood that the after part of the vessel was much more under water than the bows. She commenced to rise aft at 7.27 A.M., and at 7.28 A.M. had risen $\frac{1}{2}$°; at 8.12 A.M., $\frac{7}{8}$°; at 8.30 A.M., $1\frac{1}{8}$°; and at 8.50 A.M., $1\frac{3}{8}$°. Between 8 and 9 o'clock operations had to be suspended in consequence of the bursting of one of the

pipes of the pumping gear, the breakage being due to a fracture received while ballasting the vessel with pig-iron. This, with one or two other mishaps, caused a delay of between two and three hours, the vessel having in the meantime listed a little more to starboard, and gone down a little aft, but half-an-hour's work at the pumps rightened her, and at 1 o'clock the vessel was practically on an even keel. The head remained a-ground, but the stern had risen about 12 feet higher when operations were suspended at 6 P.M.

It had then been discovered that there was an in-flow of water forward, in consequence of some of the glass sidelights being broken; while the water in the hold of the ship could not be kept under control, owing evidently to the bulkheads not being all securely closed. The effect of this was that, as the vessel floated aft, the water in the hull surged forward and assisted to keep her head down, while the inflow through the broken sidelights added to the weight of water in the fore part of the ship. The first work undertaken on Wednesday morning, the 28th of February, was the finding of the exact locality of the apertures, and taking steps to make the vessel watertight. This was satisfactorily accomplished during the forenoon, and the water in the hull was afterwards reduced below the line of sidelights that were leaking. In the meantime divers were engaged in exploring the interior of the ship for the purpose of testing the soundness of the bulkheads. It was discovered that some of the bulkhead doors were open, permitting the water to wash freely fore and aft. These doors were securely closed, so that there was no leakage in the hull.

Operations were resumed at 6.50 A.M., on Thursday the 1st of March, and ten minutes later the pumps were set to work again. At 8 o'clock the vessel commenced to rise forward, and continued to lift gradually but steadily. At half-past 8 o'clock four steam-tugs took the "Austral" in tow, while the powerful tug "Commodore" remained astern, with a line fixed to the steamer, in order to steady her while moving up Neutral Bay. As she rose the "Austral" went ahead slowly, and after grounding once or twice, had been taken about 300 or 400 yards up the bay by 1 o'clock.

The "Austral" was beached as high as possible at the top of flood tide, and as the tide receded the cofferdam was removed. Pumping was then continued until the main-deck plates were above the water-level; and the vessel was in due course trimmed preparatory to being taken into dry dock.

The number of men employed on this work has been about

eighty-five, besides sixteen divers. Two of the latter were specially selected in London, and sent out to Sydney at the beginning of the operation.

Figs. 3 and 4 illustrate the application of the same method to

METHOD OF BUILDING UP THE HULLS OF FOUNDERED VESSELS TO ABOVE SEA-LEVEL.

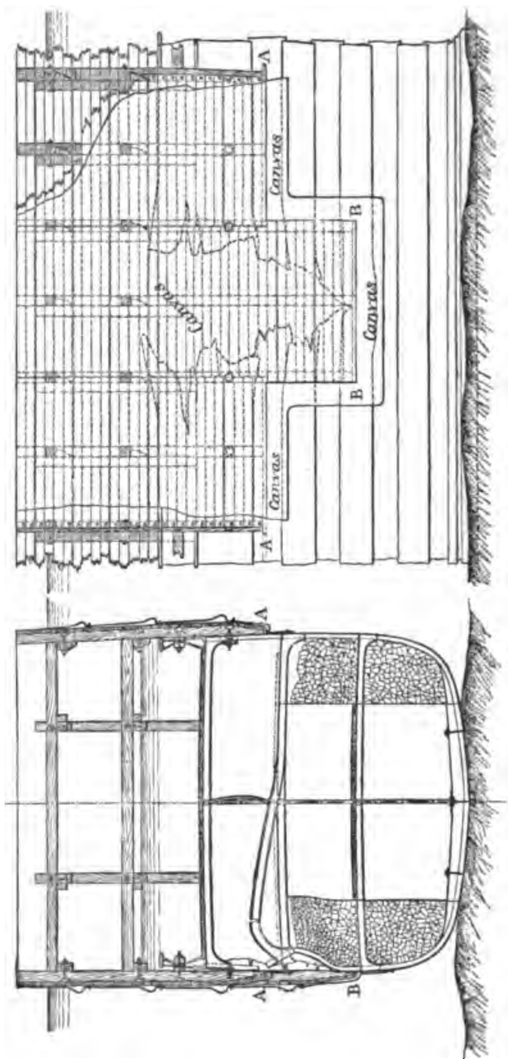

FIG. 3. Section.

FIG. 4. Side Elevation.

Scale 1 inch = 20 feet.

the recovery of vessels sunk through collision in water not much exceeding twice their own depth. A A show the depth of the

cofferdam enclosing the greater portion of the vessel, and B B a continuation of the same cofferdam sufficiently deep to cover the damaged portion of the hull. This method can of course be most successfully applied in comparatively sheltered situations.

The Paper is accompanied by several drawings, from which Plate 14 and the woodcuts in the text have been prepared.[1]

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[1] Seven photographs, illustrating fully the construction of the cofferdam, have been forwarded to the Institution by Mr. Walter Shellspear, Assoc. M. Inst. C.E., of Sydney, N.S.W., who observes that "the ship is now (March 12, 1883) afloat, and, with the exception of the damage done by the water, she is as sound as ever, and there is not even a scratch to show where the timbers were fixed."—Sec. Inst. C.E.

(*Paper No. 1947.*)

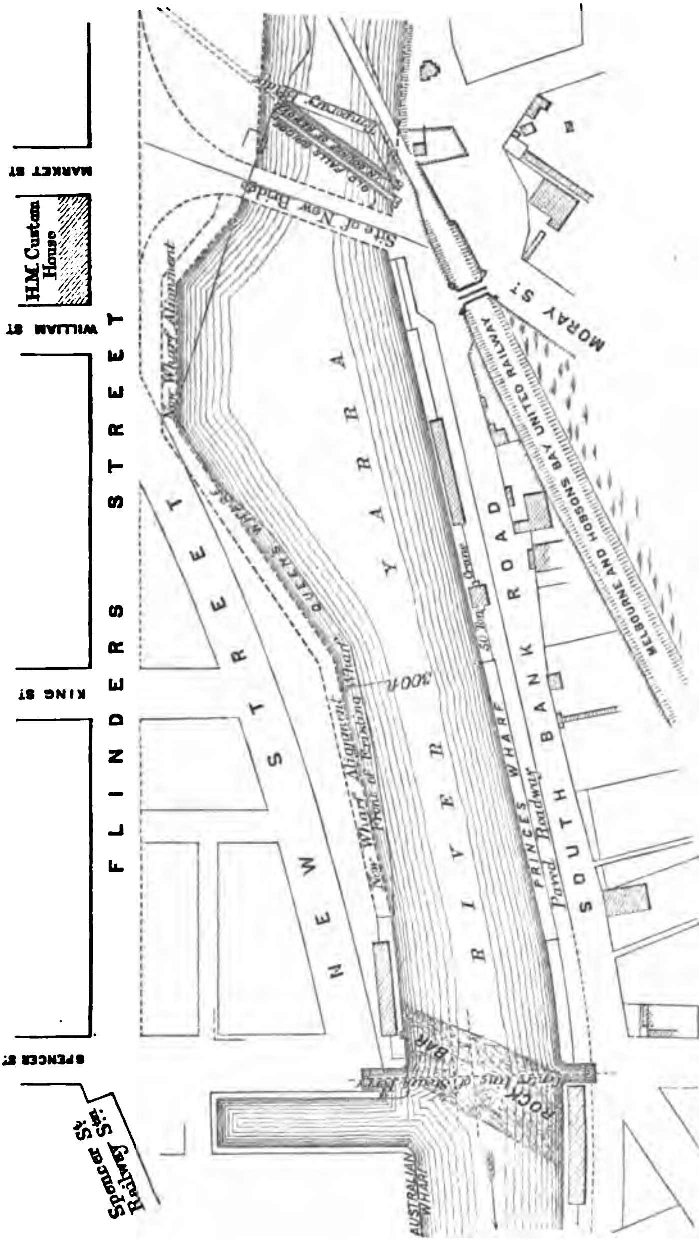
"On the Blasting of a Channel through a Bar of Basaltic Rock in the River Yarra at Melbourne, Victoria."

By Joseph Brady, M. Inst. C.E.

One of the earliest difficulties encountered by the Melbourne Harbour Trust, in deepening the bed of the River Yarra, was the removal of a bar of hard basaltic rock which crossed it about 600 yards below the head of the navigation, and limited the use of the best berthing-space in the river to trading vessels of a small draught, the channel through the rock being only 40 feet wide and 12 feet deep at low water. The river, at this portion of its course, flows in a westerly direction; and the average range of the tide is about 2 feet, increasing to from 3½ to 4 feet during exceptionally strong westerly winds.

The bar of rock is 150 feet wide, and crosses the river diagonally in a north-easterly direction; it was overlaid by a bed, 3 to 4 feet in thickness, of hard, tough yellow clay, which had to be loosened by blasting before it could be dredged and the rock laid bare. Prior to the establishment of the Harbour Trust, blasting operations had been carried on at this place for a considerable period by the Public Works Department; but, owing to the inadequacy of the means employed, the results attained were insignificant, and the Harbour Trust Commissioners, recognising the necessity for more vigorous action, took immediate steps to remove the obstruction.

A detailed survey of the reef was made by the Author in August 1878, and tenders were at once invited for the removal of the rock from the southern half of the channel, 150 feet in width to a depth of 19 feet at low water, the intention of the Trust being to limit operations to one-half of the river at a time. Four tenders were received for the work, in November 1878, ranging from £26,243 to £32,500, exclusive of the cost of a cofferdam which the tenderers contemplated using in carrying on operations. The lowest tender being more than double the Author's estimate for submarine work, the Commissioners declined to accept it, and postponed further action until the advice of Sir John Coode, M. Inst. C.E., could be obtained. This was received in May 1879,



Scale, 1 inch = 400 feet.

and being in favour of submarine operations, it was resolved to commence the work by day-labour and ascertain its cost, before submitting it again to public tender. The direction of the work was entrusted to the Author, and the results were so satisfactory that the intention of inviting fresh tenders was abandoned.

The early operations were, to some extent, experimental, and a small plant only was employed, with the intention of superseding it by more powerful appliances when the most economically effective system of rock removal had been ascertained. A good rock-drill being a primary essential, public tenders were invited for the supply of one capable of drilling 1½-inch holes in basaltic rock at the rate of 6 inches per minute, together with air-compressing and steam machinery for its working. The tender of Mr. R. G. Ford, of the Victorian Railway Department, was accepted for his rock-drill, after a satisfactory public trial had been made. This rock-drill is distinguished by simplicity of detail, regularity of working, and small wear and tear. Three of these drills were employed in the operations, two in ordinary working, and the third for use in case of a break down of either of the others; these have been maintained in thoroughly efficient order at a moderate outlay.

Two modes of applying the drill were suggested; first, by divers on its ordinary tripod-stand under water; and secondly, inside of a diving-bell. Both plans were rejected on the score of expense, and it was finally arranged to work long drills from the deck of a pontoon stage, so as to admit of the machinery being all above water and easy of access. The shanks of the drills were made of bar-iron $1\frac{1}{8}$ inch square, and the bits of steel $2\frac{7}{8}$ inches in diameter, the star-drill form being adopted after many trials. Sixty-five of these, varying in length from 18 to 30 feet, were in use, and were kept sharpened by an ordinary blacksmith.

The floating stage was composed of two 20-ton pontoon punts, secured parallel to each other 3 feet apart, thus leaving sufficient space for the working of the drills. On each side of the drills were laid rails, bearing two light travelling derricks, in each of which a guide-pole, 6 inches square, worked freely, carrying on it a rock-drill, and fitted with rack and pinion gear for adjustment to the various depths required. The guide-poles were shod with iron, and rested, when in use, on the bottom of the river, the stage rising and falling freely according to the state of the tide, or the swell of passing steamers, without in any way affecting the steadiness of the guide-poles. The stage was secured against

lateral movement by strong mooring-chains from each of the four corners, and worked by crab-winches.

The pontoons were strongly connected by means of Oregon pine-beams 12 inches square. One of them carried the machinery, which comprised a 10-inch horizontal engine, a Field boiler, an air-compressor and an air-receiver. On the other pontoon was fixed a workshop containing diving-dresses, spare drills, a work-bench, prepared cartridges for blasting, and the frictional exploder. The latter pontoon was weighted with stone ballast to trim its deck level with the other, which had the machinery to carry.

The drills were worked by compressed air at about 90 lbs. pressure, supplied by means of flexible tubes from the air-receiver; the divers were also supplied with air from the same source, as also was a flexible tube with directing nozzle, used in cleaning out the shot-holes before charging.

Apart from the blasting-stage was a small floating workshop for the exclusive use of the cartridge-maker, and a 40-ton flat pontoon punt carrying a pair of 2-ton derrick cranes, actuated by steam for lifting rock. A spoon-dredge, worked by steam, was employed in the final dredging. The above comprised all the floating plant.

The drilling and blasting were carried out in belts 30 feet wide, parallel to the axis of the river, the shot-holes being drilled in rows at right angles thereto, seven in each row to the full depth required, varying from 4 to 14 feet, and 3 inches in diameter: the rows of holes were from 3 to 3½ feet apart. After each hole had been drilled it was cleaned out by a jet of compressed air, and plugged with a conical iron plug until required for blasting.

The explosive employed was Nobel's No. 1 dynamite, and about 10 tons were used in the work; it was placed in oiled calico cartridges, in charges varying from 3 to 8 lbs. to each hole according to depth. High-tension blasting fuses were used with strong insulated copper-wire connections, the wires being separated by thin laths 6 feet long, and well secured to the cartridges. Strong detonation was found necessary to explode the dynamite under water, otherwise it was liable to ignite and burn without exploding. The cartridge room was heated by steam during winter to prevent the freezing of the dynamite.

The holes were charged by a diver, who prepared the set of seven in a few minutes; a small buoy was made fast to the wires to mark the position of the charges. No tamping was necessary, the pressure of the water keeping the cartridges in place. Everything being ready, the stage was hauled away 30 or

40 feet by means of the winches, and the firing was effected by a frictional exploder. No inconvenience was occasioned to the shipping by the operations, as, beyond a dull shock and the upheaval of the water about 1 foot, no apparent effect was produced by the explosions. The large masses of rock dislodged, being under water, did not move more than a few feet.

A sufficient area of the rock having been broken up by blasting, the rock-lifting pontoon was brought into use. Two parties of divers were employed, working in four-hour shifts, the divers below being attended to by their mates on deck. On this pontoon the air was supplied by force pumps in the ordinary way. Heinke's apparatus was used throughout; not that it possessed any advantages over those of other makers, but that the first sets purchased were of Heinke's make, and, having given satisfaction, it was considered advisable to adhere to the pattern, as the parts were interchangeable. Sling chains and iron skips were employed in lifting the stone, which was loaded into ordinary pontoon punts of light draught. Various mechanical contrivances were tried for picking up the broken rock; but lifting by hand by divers was ascertained, after many experiments, to be the most economical.

The operations were carried on night and day; but, the plant being small, only seven men could be worked in each shift. The following were the daily rates of pay: foremen, 12*s.*; engine-drivers, 9*s.*; drillmen, 8*s.*; divers, 15*s.* when diving, 8*s.* when working as ordinary hands; blacksmiths, 10*s.*; strikers, 7*s.*; deck-hands, 7*s.* Eight hours constituting a working day.

The work was begun in November 1879, and finished in February 1883, a period of three years and four months, at a cost, exclusive of plant, of £17,351 2*s.* 2*d.* The plant cost £3,597 4*s.* 6*d.* Having been maintained in first-class order, it was nearly as good as new when the work was completed, and is now employed on other rock-work in the river.

The material raised comprised 22,191 cubic yards of hard clay, and 20,087 cubic yards of rock. The average of the working expenses was 4*s.* 6*d.* per cubic yard for clay, and 12*s.* 3¾*d.* per cubic yard for rock, placed in barges ready for removal, exclusive of interest on the cost of plant. Four thousand nine hundred 3-inch holes were drilled in carrying out this work, and 22,132 lbs., or nearly 10 tons, of dynamite were used. Of the 20,087 cubic yards of rock, 7,711 were used for sea-walls and pitching of slopes; 5,900 for pitching and macadamizing roads, and the

remainder, 6,476 cubic yards of inferior rock, was employed in filling for road approaches and backing to wharves.

After upwards of three years of continuous work the rock obstruction has been successfully removed, at a moderate outlay and without the slightest accident; and, where formerly there was a channel of only 40 feet in width and 12 feet in depth at low water, there is now a clear passage 300 feet wide and 19 feet deep at low water, with substantial wharves at each side. Here are berthed the principal intercolonial steamers trading to Sydney, Brisbane, Adelaide, Western Australia, Dunedin, Hobart, and Fiji, which formerly lay at the piers in Hobson's Bay.

The Paper is accompanied by a tracing, from which the woodcut has been prepared.

(*Students' Paper, No. 159.*)

"On Iron and Steel in Tension, Compression, Bending, Torsion, and Shear."[1]

By Percy Vavasseur Appleby, Stud. Inst. C.E.

There is so much valuable information relative to experiments on iron and steel that further investigation may appear unnecessary; but the Author has not seen records of experiments and tests of specimens of iron and steel, cut from the same bar, or cast from the same ladle, under each of the five conditions mentioned in the title. This has led him, in his course of three years as a student at University College, London, to make a large number of tests, the results of which are embodied in the present Paper.

Before proceeding to describe the tests in detail, it may be well to mention that the term iron includes both cast and wrought iron, and the term steel refers to open-hearth steel in castings and forgings, crucible-steel in castings and forgings, and Bessemer steel forgings. As regards the materials for the specimens, an identical note was written to several manufacturers, stating the purpose for which the materials would be employed.

The testing-apparatus used was that in the Engineering Laboratory, University College, London, of which the machines have been fully described,[2] and are generally well-known.

The shear-apparatus, however, is new; this is shown in Plate 15, Figs. 17 and 18. It will be seen that the specimens are under double shear, the two grooves being turned so as to avoid the possibility of any cutting action. The apparatus for holding the torsion-specimens is also shown in Figs. 19; the carriers, which are fixed on each end of the test-piece, are arranged in such a way, that the more the piece is twisted, the tighter it is gripped by the eccentric steel arm K.

With the exception of the specimens in shear, measurements of the strains were taken on all pieces tested, and a modulus of elasticity (direct or transverse), has been calculated from each

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[1] This communication was read and discussed at a Meeting of the Students on the 9th of March, 1883, and has been awarded a Miller Prize.

[2] "Engineering," Sept. 26, 1879, and Jan. 21, 1881; also "The Engineer," Feb. 25, 1881.

piece. The actual readings on each piece are not given, because a detailed account of the tests of over one hundred and forty pieces would occupy too much space. But curves connecting the stresses and strains of each piece tested have been drawn, and from these the typical curves for each material under each kind of test have been selected (Plate 15, Figs. 1 to 12).

The strains in tension, compression, and bending, were measured by the apparatus shown in Figs. 20. This consists of a light frame A, carrying a simple lever B. The two steel points, C C, are 10 inches apart; these are placed in centre punch-marks on the specimen, the apparatus being held in position by elastic bands, and the weight D serving to preserve the balance. The lever B turns on the two set-screws E E, and at one end is a pointer F, moving on the sectional paper G. As the piece extends, the steel points, C C, are moved apart, and their motion is communicated to the pointer F. The leverage is 100 to 1, and has been corrected by actual measurement on vernier callipers; by this apparatus, the effects of strains are measured to $\frac{1}{10,000}$ inch.

In the torsion-tests, a large cardboard protractor was fixed on one end of the test-piece, and a cardboard circle of the same size, with a sector cut out of it, was attached to the other end; both being so arranged that they could turn only as the piece twisted. Readings to one edge of the sector were taken on the application of each different stress by the aid of a telescope fixed 10 yards distant in line with the test-piece.

In the first left-hand column in the table of tests is given the test-marks of the pieces, and in the next a brief description of the materials.

The term "specific extension" in the tension-tests, is merely a convenient quantity for the comparison of the rates of extension of different materials within the limit of elasticity, the ordinary units of 1 lb. and 1 inch used to express the specific extension as "The extension in inches produced by 1 lb. stress on 1 inch length," gives quantities inconveniently small for comparison. For this reason, the "specific extension" is defined as "the average extension measured in $\frac{1}{1,000}$ inch, produced by 1,000 lbs. per square inch stress on a length of 10 inches within the limit of elasticity." This quantity was first introduced by Professor Kennedy, M. Inst. C.E., and is defined in his Paper on "The Results of Experiments on Riveted Joints made for the Institution of Mechanical Engineers." [1]

[1] Proceedings, 1881, p. 205.

As is well known, the "modulus of elasticity," is the ratio of the stress per square inch to the extension or compression which it produces, on 1 inch length within the limit of elasticity. Thus, if x is the extension in inches produced on a length l by the stress s, then the modulus of elasticity $E = \frac{s}{\frac{x}{l}} = \frac{s\,l}{x}$.

In this expression, if x could equal l, then $E = s$, thus obtaining a further definition of the modulus of elasticity, viz., "That ideal stress which would stretch a perfectly elastic bar to double its original length." In the expression $E = \frac{s\,l}{x}$, if the specific extension (ϵ) be substituted for x, and s and l replaced by their corresponding values, then $E = \frac{1{,}000 \times 10}{\frac{\epsilon}{1{,}000}} = \frac{10^7}{\epsilon}$ which gives the relation between the specific extension and the modulus of elasticity. It is worthy of note, that the specific extension is always the observed quantity, and the modulus of elasticity is derived from it by calculation.

Where bending- and torsional-stresses are given per square inch, the maximum stress per square inch on the outermost fibre is referred to.

The "limit of elasticity" is the stress at which the ratio $\frac{\text{strain}}{\text{stress}}$ ceases to be a constant quantity, the strain increasing in a higher ratio than the stress; this is clearly shown in Figs. 4 and 7, by the line of strains; which was straight up to this point, commencing to curve upwards.

The "steelyard drop" may be regarded as the commercial limit of elasticity; at this stress the material seems to break down, and it extends without increase of load, generally about ten times as much as the whole extension up to this point. Mr. Tweddell, M. Inst. C.E., has suggested that this period in the elastic life of a piece should be termed "the limit of fatigue."

The "specific compression" (values of which are given in the second column of the compression tests), corresponds exactly with the specific extension, being the average compression in $\frac{1}{1,000}$ inch produced by 1,000 lbs. per square inch stress, on a length of 10 inches, within the limit of elasticity, The modulus of elasticity is calculated from it by the formula $E = \frac{10^7}{c}$.

In the bending-tests, the modulus of elasticity is obtained by the formula $E = \frac{1}{12} \cdot \frac{s l^2}{y d}$, d being the average deflection in inches produced within the limit of elasticity by the stress s, on a beam of span L and half-depth y.

The modulus of transverse elasticity is obtained from the torsion-tests; this quantity is the ratio of the stress to the proportional strain on a piece in torsion. The strain being measured by the tangent of the angle of distortion, $C = \frac{\text{stress}}{\tan \angle \text{ of distortion}} = \frac{2 s l}{t d}$, where t is the average twist in circular measure produced within the limit of elasticity, on a piece of length l and diameter d by the stress s.

Cast Iron.—The specimens A and B were cast by the Tyne Foundry Company, at Deptford, from the following mixture of metals:—

A. Half Gartsherrie and half machine-scrap.

B. Half cold-blast iron and half machine-scrap. Each set of specimens was cast from the same ladle.

It will be observed that the B specimens have a greater strength in tension and bending than the A specimens.

A tendency was shown in all cases for the compression-specimens to break in the manner shown in Fig. 13. This seems to be explained by considering that as the piece buckles, a shearing-stress is set up in the planes A B, A C, and the piece gives way by shearing in these planes as soon as the maximum shearing resistance is reached; at the same time the ends, which are in shear, give way.

The ratio $\frac{\text{length}}{\text{diameter}}$ was 8·6 for specimens A and 11·5 for specimens B. A small piece for which the ratio $\frac{\text{length}}{\text{diameter}}$ was 1·57 broke into fragments at 46·4 tons on the square inch, by shearing. Another piece, for which the ratio $\frac{\text{length}}{\text{diameter}}$ was 3·63, broke at 41·4 tons by shearing at one end. In the cast-iron bending tests, special care was taken to make the pressure vertical with the length of the beam.

The shearing-stress for the B specimens was 12·3 tons, and the torsional-strength was 18·9 tons per square inch for the turned pieces. The breaking-stress of the unturned torsion-specimens was rather low, as the three pieces tested were slightly unsound.

Of all the specimens tested, those alone which are marked C

were not supplied as test-pieces. The material was wrought-iron plate, of a quality frequently used for girders and shipbuilding; the low tenacity, small extension, and small reduction of area, were remarkable. The fractures were laminated, with about 60 per cent. crystalline, and the welding was indifferent. In bending, specimens of ½-inch plate, 1 inch deep, broke before they had bent through 30°.

The fourteen specimens D were made at the Stanners Closes Steel-works by the Attwood open-hearth process, and all were cast from the same ladle. The material was ordinary steel-casting, which will not bend much when cold, but when heated it can be bent to any shape, or when drawn out under the hammer hot (into a chisel) it can be hardened and tempered in the ordinary way. As is usual in steel castings, some of the specimens were porous, and the values obtained from the tests of the porous pieces have been withheld in taking the average. The torsion-pieces were especially troublesome; but this is no doubt greatly due to the difficulty in making sound castings of such small dimensions. The tension-specimens broke, with a finely crystalline fracture, under a strain averaging 29·06 tons per square inch, the final extension being imperceptible. The three compression-specimens were all unsound, two breaking at blowholes, and one specimen at a black cinder; so probably the values for the limit of elasticity, &c., will in practice exceed those given in the tables. In bending, the fractures were largely crystalline, the piece always breaking diagonally across. The deflection previous to fracture was very small.

Of the five torsion-specimens, the only sound one had a limit of 20·09 tons and breaking-stress of 39·29 tons per square inch. This is a high value as compared with most other materials. The piece did not twist 1 turn in a length of 30 diameters, showing great resistance to strain in torsion. Its fracture closely resembles that of the cast-iron torsion pieces. In shear, this material has also a high resistance, namely, 29·7 tons per square inch. The specimens broke like cast iron, and not in the grooves.

The fifteen specimens E were from the Stanners Closes Steel-works, and were forgings made from an open-hearth steel furnace. In tension, the tenacity was about 30 per cent. greater than the castings, and the extension 17 per cent. on 10 inches, the reduction of area being 36·3 per cent. The fractures were in two cases cup-shaped. The compression-pieces had a somewhat lower limit than the castings D, but they bent double without sign of cracking (Fig. 14). The bending-specimens were not broken at 66·4 tons per square inch, having then bent through a right angle. In tor-

sion the limit was reached at about one-half the load of the cast-steel specimens D. Fracture occurred at 29·6 tons per square inch, the specimen having then twisted on an average 7·14 turns on a length of 30 diameters. In shear, the average breaking-stress was 25·9 tons per square inch.

The next material, F, was wrought iron of the well-known "B. B. H." brand, and the results obtained were:—

Commercial limit, 17 tons per square inch; breaking-stress, 25·4 tons per square inch; extension on 10 inches, 22·3 per cent.; reduction of area, 23·9 per cent.

The fracture was fine, silky, and non-crystalline, and the welding was sound. In compression the specimens doubled up without sign of cracking (Fig. 14), and they were bent to a right angle without breaking. In torsion, the limit was 8·9 tons, and breaking-stress 26 tons per square inch, the total twist being 10·56 turns on a length of 30 diameters.

The specimens G were of the "S" quality of Landore-Siemens steel, which is used for ship- and boiler-plates where not exposed to flame, and the specimens H were of the "S. M." quality, which is used for forgings. The tabulated tests of these two materials show that H is a tougher material throughout. The fractures of the G tension-specimens were silky, with little white spots caused by the presence of small cones, due to irregularities in ductility. The specimens H had uniform, silky, cup-shaped fractures. Both materials doubled up without breaking in compression; but in bending, they broke after deflecting through nearly a right angle. Comparing these results with those of the open-hearth steel forgings E, the latter seems a still tougher material than either G or H.

The specimens K were wrought iron made by Messrs. Fry, Ianson and Co. of Darlington, and the results obtained were:—

Commercial limit, 15·16 tons per square inch; breaking-stress, 22·46 tons per square inch; extension on 10 inches, 14 per cent.; reduction of area, 19 per cent.

The fracture was laminated, with 10 per cent. crystalline, and the welding was fair. The bending-specimens were deflected through a right angle without cracking. The limit of elasticity in torsion was 8·9 tons, and breaking-stress 22·3 tons per square inch, with a total twist of 3·2 turns on a length of 30 diameters. The piece was much distressed and bent before it broke.

The material L was Bessemer-steel bar made by Messrs. John Brown and Co. of Sheffield, and was described by them as a medium-temper steel, such as is usually supplied in steel forgings.

It bore a close resemblance in all its tests to the open-hearth steel forgings E. The fractures had a uniform silky appearance, those in tension being cup-shaped. The 10-inch length on which strains were measured, is shown for one of the tension-specimens in its final and extended form in Fig. 16. The bending-specimens were deflected through a right angle before fracture. This feature is important as showing where the strain was smallest, namely, in a plane through the axis of symmetry of the cross-section parallel to the edge of the beam.

The scaling was observed to take place soon after the limit was reached, and long before the ultimate load was put on. The same phenomenon was observed in many of the wrought-steel and iron beams, but was specially marked in the instance mentioned.

The specimens M were of Bowling iron, and the results obtained were :—

Commercial limit, 14·4 tons per square inch; breaking-stress, 20·9 tons per square inch; extension on 10 inches, 19·8 per cent.; reduction of area, 29·8 per cent.

The fractures were uniform and silky, and the welding sound. The test across the fibre in tension is also given. In compression, the pieces were doubled up; and in bending, they were deflected through a right angle without breaking. In torsion, two bars were tested, also a square piece of ½-inch plate; the latter had a limit of elasticity of 8·9 tons, and breaking-stress of 20·099 tons per square inch, twisting 3 turns before fracture.

After having been tested up to 25 tons per square inch stress, and twisted 10 turns on a length of 30 diameters, one of the torsion-specimens was subjected to a tensile-test. It was found that the limit of elasticity had been increased to 20·34 tons, the breaking-stress being 22·47 tons per square inch. The extension on 20 inches was only 0·25 per cent., the fracture being very finely crystalline, and the twisting of the fibres quite perceptible.

The specimens N were Bowling crucible-steel casting, taken from an ordinary heat for castings such as forge-hammers and mill pinions. The values of the tensile-test are probably somewhat lower than would be obtained in practice, because the two specimens tested broke at blowholes; the fractures were finely crystalline. The shear-specimens were somewhat unsound. The material throughout was very tenacious, but non-ductile, and in these respects it resembled the open-hearth castings D.

The specimens O were of crucible-steel rolled bar, and the results obtained were :—

Commercial limit, 25 tons per square inch; breaking-stress, 47

tons per square inch; extension on 10 inches, 9·5 per cent.; reduction of area, 25 per cent.; the fractures were finely granular and uniform. One of the tension-specimens drew down considerably in two places just before fracture, and then broke at the larger diameter. The compression-specimens broke as shown in Fig. 15. In bending, the limit of elasticity was 64·3 tons, and the breaking-stress 121·2 tons on the square inch, though the deflection was not very great. In torsion, the limit of elasticity was 18·5 tons, and the breaking-stress 44·6 tons per square inch (a high value), the total twist being only 1 turn on a length of 30 diameters.

The specimens P were from very hard steel, specially made for turning-tools to work without hardening in water. The tension-specimens were so hard that they could not be turned, but one of them was forged to such a shape that it might be held in the testing-machine. This piece broke at 36·25 tons, but not at the smaller sectional area, indicating that the material was injured by forging; the fracture had a vitreous appearance. In compression, the limit of elasticity was not reached at 45 tons; but the steel-yard drop was observed at 51·3 tons per square inch. These pieces stood the whole load of the machine, a stress of 52·05 tons per square inch, without buckling perceptibly. In bending, the breaking-stress was 57·4 tons per square inch, no limit or steel-yard drop being perceptible. The total deflection just before fracture was not more than $\frac{1}{8}$ inch. Similar fractures of tool-steel have been obtained by Mr. J. J. Webster, Assoc. M. Inst. C.E., under a monkey-test.[1] A piece of this steel was tested in torsion up to 20 tons per square inch stress, and there was no sign of a "limit" or of fracture.

Specimens Q and R show the relative values of crucible-steel forging and casting. The commercial limits were respectively 18·3 and 20·2 tons per square inch; the extension of the forging, however, was 26·5 per cent., and its reduction of area 65·4 per cent., while those for the casting were 1·8 per cent. and 7·7 per cent. respectively.

The experiments recorded in this Paper seem to lead to the following general conclusions:—

The values of the specific extension and of the modulus of elasticity for wrought iron and steel are nearly the same, but the tests indicate that, as a rule, the softer and purer the iron or steel, the higher is the modulus; whilst the harder steels, in

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[1] Minutes of Proceedings Inst. C.E., vol. lx., p. 161.

which a greater percentage of carbon is present, have a lower modulus of elasticity. Thus:—

		Inches. Per Cent.		e	E
E	Soft forged steel with extension on 10 =	17·0	has	0·309	32,474,300
G	Soft open-hearth steel	21·6	„	0·316	31,688,300
F	B.B.H. wrought iron	22·3	„	0·323	30,950,700
M	Bowling iron	19·8	„	0·333	30,027,600
L	Bessemer steel	19·7	„	0·336	29,759,500
H	Harder open-hearth steel	20·2	„	0·337	29,722,000
N	Cast crucible steel	nil	„	0·349	28,796,000
O	Crucible steel bar	9·5	„	0·350	28,546,000
D	Cast open-hearth steel	nil	„	0·383	26,089,000

showing clearly that the modulus of elasticity decreases as the hardness of the material increases.

Cast iron, which is furthest removed from pure iron, has a modulus varying between 11,250,000 and 16,500,000 lbs. From other experiments made by the Author, its average value seems to be about 12,500,000 lbs.

The values given for the modulus of transverse elasticity do not show the peculiarities just referred to in so marked a manner, though its values for the crucible-steel specimens O and P are low, and for cast iron far lower. It will be noticed that the modulus of elasticity varies for each material in the tension, compression, and bending-experiments. The difference between the moduli in tension and compression does not, as a rule, exceed 10 per cent. This is no doubt in part due to variations in the quality of the material in different specimens. The difference between the moduli in tension and bending generally exceeds 10 per cent. This, too, may to some extent be attributed to the cause above mentioned; but probably the internal conditions of a beam under stress are not yet entirely understood.

Attention is directed to the fact that, in all cases, the ultimate strength of each material is greater in the form of a beam than in that of a tie. This anomaly has given rise to considerable discussion, and the fraction $\frac{\text{ultimate strength in bending}}{\text{ultimate strength in tension}}$, which in all cases is greater than unity, is denoted by ϕ. Mr. B. Baker, M. Inst. C.E., in his work on "The Strength of Beams, Columns, and Arches," has used the symbol ϕ in a somewhat different sense, namely, as the 'difference' between the ultimate stresses as a beam and a tie; these two values are readily convertible.

Previous experiments have uniformly shown that ϕ varies for beams of different section, its value being greatest when the

material is most concentrated at the centre. This has raised the question whether the usual method of calculating the stress in a beam (which is theoretically correct) gives a real value. The question seems to be answered by the fact that values of the modulus of elasticity have been calculated from the deflections of beams, agreeing closely with the values obtained in tension, in which the ordinary method of determining the stress in beams has been employed.

It has again been urged, that the apparent anomaly is accounted for by supposing that, after the material has passed the limit of elasticity as a beam, the position of the neutral axis is altered, and consequently the general method of calculating the stress no longer holds good. That this reasoning does not answer the question satisfactorily seems to be proved by the fact that a value ϕ has been obtained, by comparison of the limits of elasticity in tension and bending, which agrees closely with that obtained by comparison of the ultimate stresses. Moreover the scaling of the beams before mentioned occurred after the limit of elasticity had been reached, showing that the neutral axis had not been shifted perceptibly to one side of the beam; and it can easily be proved that the neutral axis must be very much shifted to cause the difference in the bending and tensile stresses which actually occurs.

The only satisfactory way in which this ratio ϕ can be explained, appears to be that set forth by Mr. Barlow, Past President Inst. C.E.,[1] namely, that the lateral action of the fibres tends to modify the effect of the unequal strains and opposite forces, thus diminishing the amount of extension and compression which would otherwise arise, and constituting an element of strength which Mr. Barlow has named the resistance of flexure.

A similar anomaly appears in connection with torsion and shear; the ultimate strength in torsion being in all cases greater than in shear. The ordinary method of calculating the stress in a shaft is proved to be correct, because the modulus of transverse elasticity (C), in determining which the values of the stress obtained by using ordinary formulas have been used, agrees closely with values for C obtained in shear.

For reference, the ratio $\frac{\text{breaking stress in shear}}{\text{breaking stress in tension}}$ is calculated for each material; with the exception of the cast-steel D, this ratio is a proper fraction.

Referring to Plate 15, Figs. 1 to 9, the stresses are set off as

[1] Philosophical Transactions, 1855 to 1857.

abscissas, and the corresponding strains as ordinates. lines on each diagram, represent the two sets of readin actual strains, and of the permanent strains or "sets;" lines refer to the total strains, and the dotted lines to th nent strains.

The strains and sets in the first trial are always greate the second. This, as is well known, is due to the pr initial strain in the piece, which is not present after trial. In the tests under all of the four conditions, th line is very nearly straight up to the limit of elasticity then begins to curve upwards rapidly. In testing cast "limit" is reached, the elastic line curving slowly upwa the commencement of the test.

A special point, demonstrated in these diagrams, is "elastic strain," or the strain in excess of the permanent the same in both trials, so that the strain for a given stre first trial exceeds that for the same stress in the second an amount nearly equal to the "set" in the first trial. Th good for all the materials tested, and in whatever man similar result has been observed by Professor Kennedy, referred to by him in the discussion on his Paper on " Joints."[1] In testing a specimen to obtain its modulus, it seem best to strain it to about three-quarters of the limit commencing to record the readings. The initial strain taken out of the piece, and the readings would be substa the same as those shown as the second curve in Figs. 1 to 9.

It may be well to mention that the construction of the t machine is such as to allow freedom to the piece under lengthen or shorten. In these experiments it was found the tendency under twist was to lengthen, but only to a extent, never exceeding 0·25 inch on a length of 30 inche observable only in the softer materials.

The order in which the limit of elasticity was succes reached was practically the same throughout, and cast iro always strained to a much greater extent for a given stress any other material within the limit of elasticity.

The ratio of the modulus of transverse elasticity to the mo of direct elasticity $= \frac{C}{E}$, and designated by the symbol μ, v cast iron being excluded, from 0·375 to 0·486, its average v

Specific Compression. (c)	Mod. Ela
0·584	17,
0·581	17,
0·626	16,
0·632	15
..	
0·344	29
0·330	30
0·352	28
0·324	3
0·347	2
0·391	2
..	
0·362	
..	
0·374	
0·352	
0·376	
..	
..	

[1] Institution of Mechanical Engineers. Proceedings, 1881, p. 288.

Specific compression. (c)	Modu[lus of] Elast[icity] ... (...	Ratios.				
		Bending stress / Tensile stress ϕ	Limit in bending / Limit in tension ϕ_1	Torsile stress / Shearing stress Φ	Shearing stress / Tensile stress	$\frac{c}{E} = \mu$ (E in tension).
0·584	17,16	..	..	..	..	..
0·581	17,2	1·9167	..	..	..	..
0·626	16,0	..	..	1·1729	0·9857	0·3362
0·632	15,8	2·0265	..	..	..	0·3665
..		1·8941	..	..	..	..
0·344	29,0	1·3591	1·2048	1·3228	1·0220	0·4653
0·330	30,3	..	1·4443	1·1441	0·6650	0·3884
0·352	28,40	..	1·5386	1·1607	0·8830	0·4019
0·324	30,94	..	1·5712	1·2520	0·8679	0·4077
0·347	28,8	..	1·5653	1·2330	0·8340	0·4217
0·391	25,5	..	2·0000	1·1444	0·8685	0·3754
..		..	1·4000	..	..	0·4859
0·362	27,6	..	1·5621	1·4384	0·9035	0·4416
..		..	..	..	..	..
0·374	26,7	1·8965	1·5548	1·5646	0·8395	0·4681
0·352	28,3	2·5761	2·0400	..	0·7043	0·4109
0·376	26,6	..	..	..	..	0·4314
..		..	..	..	..	..
..		..	..	..	..	..

To face p. 268.

being 0·4271 apparently increasing in proportion to the hardness of the material. It has been proved that for a perfectly elastic material, $\mu\left(=\frac{C}{E}\right)=0\cdot4$. For most of the materials tested μ was greater than this; but the average value was not much in excess of the theoretical value. For cast iron, this ratio had a value about 12 per cent. below that of a perfectly elastic body.

The question as to the relative commercial value of iron and steel has been so fully discussed, that the Author feels it unnecessary here to express an opinion; but, the above experiments clearly show that steel is a more uniform and tenacious material than iron, and being, at least, equally ductile, it is to be preferred for constructive purposes.

In conclusion, the Author wishes to express his obligations to the manufacturers mentioned in the Table of Tests; also to Professor Kennedy for the facilities he has so kindly afforded during the experiments, and to Mr. G. W. Butchard, Stud. Inst. C. E., his fellow-student at University College, for valuable co-operation in the work of testing.

The Paper is illustrated by numerous drawings, from which Plate 15 has been compiled.

(*Students' Paper, No. 158.*)

"On a Deep Boring at Northampton."[1]

By Henry John Eunson, Stud. Inst. C.E.

In 1878, in consequence of the rapid growth of the town of Northampton, the water-company considered it necessary to look for a further supply of water, and from a different source to that from which their present supply is obtained, namely, from the marlstones and rock bed of the middle lias.

By the advice of their consulting engineer, Mr. John Eunson, Assoc. M. Inst. C.E., and with favourable reports from Messrs. R. Etheridge and J. W. Judd, who had been consulted relative to the continuity of the Triassic series beneath the lias clays as far eastward as Northampton, it was decided to bore through these clays, hoping to reach the beds known as the "Water Stones," at the base of the Keuper marls in the Trias formation. The probable depth at which the Water Stones would be found was estimated at about 1,000 feet, taking the Lias clay to have a thickness of 700 feet, and the Keuper marls of about 300 feet.

Similar beds had been met with at Burford, in Oxfordshire, situated on the same line of "strike" as the strata at Northampton, The trias formation was also reported to have been reached in 1830, in a shaft sunk about 2 miles north of Northampton, in the parish of Kingsthorpe, when searching for the Coal Measures. This shaft is 374 feet above sea-level, and was sunk to a depth of 967 feet, the Lias clay having a thickness of 737 feet.

The issue of the boring was necessarily subject to great uncertainty. It was thought, for instance, that the Keuper marls might be made of so great a thickness, at this point, as to render the undertaking a failure; or that the water-beds might thin out before reaching so far east as Northampton; or that even when reached, by reason of concealed faults, they might prove unproductive of water. After consideration it was decided to use the diamond drill, since the facility afforded by this system of extracting solid cores of the strata passed through, was of great value in determining the exact position, geologically, of the beds in which the boring was proceeding. Accordingly a contract was

[1] This communication was read and discussed at a meeting of the Students, on the 2nd of March, 1883, and has been awarded a Miller Prize.

entered into with Messrs. T. Docwra and Son, of Balls Pond Road, Islington, who use the boring machine of Mr. J. K. Gulland, and they worked under his immediate superintendence.

The terms upon which the work was to be carried out were as follows:—That the contractors should commence with a bore-hole 24 inches in diameter, and continue that size to the greatest possible depth, reductions in diameter only to be made under the direction of the water-company's engineer. The lining tubes were to be provided by the water company, and the contractors to be paid a certain fixed sum for placing the tubes in position; and that a further sum be paid to the contractors if the boring should be a success, such as to warrant the company in putting down permanent pumping machinery.

The price per foot bored and the core extracted, for a depth not exceeding 500 feet from the surface of the ground, was to be £5; for the next 300 feet, £6 per foot; and for the remainder of the depth exceeding 800 feet from the surface, £6 10*s.* per foot.

Preliminary Operations.

A well (Plate 16, Fig. 1) situated to the north-east of the town, on the Kettering Road, had a few years previously been sunk by the water-company to a depth of 203 feet, to the marlstones of the Middle Lias, which beds at that spot had proved unproductive of water consequent upon the gradual lowering of the water-level throughout the neighbourhood. As the contractors were engaged elsewhere with their largest boring-machine, they decided, with the permission of the engineer, to sink a 5-feet shaft from the bottom of the well.

Sheer-legs were first raised. These were four in number, 50 feet in length, 18 inches square at the base, 10 inches square at the top, and of pitch pine.

The shaft was commenced in July, 1879, and the work continued to the end of November of the same year, during which period a further depth of 200 feet was attained; a depth of 120 feet of the shaft was bricked, as the work proceeded in 5-feet lengths; the lower courses only of each length were laid in cement, the remainder being set dry, with cement poured in behind.

The Lias clay, in which this shaft was sunk, was hard and dry; but the face, under the action of the atmosphere, speedily disintegrated, and although it was not considered necessary to incur the expense of lining the last 80 feet with brickwork, precautions had to be taken by roughly boarding the face to prevent falls.

The average depth sunk and bricked was 8 feet 4 inches per week. The progress of the sinking was 1 foot 6 inches per day, but when blasting was resorted to, as much as 3 feet per day could be sunk.

From the bottom of this well, 403 feet in depth, cast-iron pipes, 24 inches in internal diameter, were carried to the surface. These were necessary, as all the boring operations were carried on under a pressure of water from the surface. The pipes were, for a depth of 100 feet, in lengths of 10 feet, connected with countersunk collars and screws. They were originally intended to line the bore-hole, had the boring commenced at the bottom of the 10-feet well; for the remaining 303 feet, socket- and spigot-pipes were adopted, the joints being made with cold lead strips calked in. The tubes for 20 feet at the lower end were embedded in concrete, and the shaft, for a further distance of 60 feet, was filled with clay thrown in from the surface, so that the pipes might be firmly bedded. Struts and stays of 8-inch timbers were also placed in the well at every 40 feet to keep the pipes in position.

The Boring-Machinery. (Plate 16.)

The boring-machine was that patented in 1877 by Mr. J. K. Gulland. The method of drilling is by erosion. The drilling-crown (Fig. 2) is a circular ring of steel, about 2 inches thick, in which the diamonds are set, screwed into the core-tube, and revolved by the machinery on the surface. It cuts its way down, and leaves a solid core of the strata passed through, which is afterwards extracted, leaving the hole clear.

The diamonds used are the black carbonates found in Brazil, about the size of small beans; they are brazed into steel plugs, and these plugs fit into the holes drilled in the ring of wrought steel. The largest crown was 23 inches in external diameter, and contained nearly fifty stones, having an aggregate weight of more than 300 carats. The crown is screwed to the core-tube (Fig. 3), which serves to keep the drilling vertical, and contains the core as it is drilled. In the first size, the core-tube was 22½ inches in external diameter, was 30 feet in length, and of wrought-iron. The rods connecting the core-tube with the surface machinery fit into a plate at the top of the tube, above which is a 5-feet length of tube of the same diameter, and open at the top (Fig. 4). This receives the coarser particles falling from suspension in the water flowing upwards after washing away the sediment in drilling, also any fragments which may be

detached from the sides, thus preventing the crown from becoming clogged in the bore-hole.

The boring-rods are tubes of drawn steel, 3½ inches outside diameter, and ⅜-inch in thickness, in lengths of 5 feet, connected by steel collars.

During the operation of boring, a continuous supply of water is pumped down through the hollow bore-rods, to keep the crown cool and carry off the sediment formed by the erosion of the strata by the crown. The water flows through channels cut in the face of the crown, finds its way on the outside of the core-tube to the surface, and is collected in settling-ponds, where the sediment is deposited. About 3,500 gallons of water per hour were required, the water, after depositing the sediment, being used over again.

The boring-machinery on the surface (Figs. 8, 9, 10, 11, and 12) consisted of a strong framework of wrought iron, having two principal pillars in front, one of cast iron, which forms the chief support of the upper part of the machine, which is also stayed by raking supports from behind; the other, a circular upright shaft running in a shoe at the bottom and a bearing at the top. This is the main shaft for transmitting the power from the machinery to the rods by a system of bevel-wheels.

The cross-head (Fig. 13), from which the rods are immediately driven, slides on the circular shaft, and the motion to the rods is given by a wheel fixed to the cross-head which works on the shaft by means of a feather key. The cross-head is thus enabled to slide on the vertical shaft and follow the rods as they sink in boring. At the back of the two upright pillars, and between the raking stays, are the different parts of the hoisting apparatus for drawing and lowering the tools. When drilling, a load is attached to counterbalance the weight of rods as the boring becomes deeper, the pressure on the crown being kept constant at about 10 cwt.

The rods, on account of the height of the sheer-legs, could be raised and lowered in lengths of 40 feet; when in practice, the men could raise a length of 40 feet by the machine, disconnect it, and lay it down in front of the machine in three-and-a-half minutes; the reverse operation, that of picking one up, connecting it, and lowering it in the hole, could be accomplished in two-and-a-half minutes.

The machine was worked by a 20-HP. portable engine, but 40-HP. were frequently indicated, and the drilling-machine, weighing upwards of 20 tons, was repeatedly rocked to and

fro under the great strain which had to be exerted in freeing tools which had become fast in the bore-hole, when the drill worked unevenly on account of a small stone or other impediment under the face of the crown, or when an extra force was necessary to break off the core. The crown was revolved at first at about forty revolutions per minute, and this speed was increased to as many as one hundred and fifty when in favourable strata. On a depth of 5 feet having been bored, the cross-head was disconnected from the rods, raised to its full height, and a 5-feet rod inserted.

After a length of core had been drilled sometimes nearly 30 feet, which was the limit that the core-tube would contain, the tube and crown were drawn to the surface, the crown was unscrewed, and the extractor (Fig. 5), fixed in its place. This tool, consisting of an annular ring of steel, 9 inches in depth, from the sides of which turning inwards were steel clutches or teeth, was then lowered over the column of core left standing in the hole, the projecting teeth laying hold of the core. The cross-head was next connected, and the core pulled asunder and drawn in the tube to the surface, and upon unscrewing the extractor the core could be removed. The hole was thus left clear and ready for the next drilling.

Frequently the core, or part of it, would be broken off and become fixed in the core-tube, coming up with the crown when first drawn. A ring of steel fitting inside the core-tube, and which clipped the core as it was drilled, was tried as an extractor, but owing to the comparatively soft nature of the clay it failed to grip it sufficiently. This ring was not tried in the harder strata.

In the larger sizes nearly the whole of the core drilled was extracted, though in some cases the clay was washed away by the water pumped through the rods; or if the core became broken, the two surfaces would be worn by the broken piece revolving with the tube, which was particularly noticed when the hard and soft beds alternated in quick succession, and when the core was sandstone large quantities were thus lost.

Lining Tubes.

The soft nature of the clay, and the large area of surface exposed to the action of the water, rendered it necessary to line the bore-hole with iron tubes. The first, following the 23-inch crown, were of cast iron in 10-feet lengths, 21 inches in internal diameter, $\frac{3}{4}$-inch thick, and connected by countersunk collars

of wrought iron, and screws. The two succeeding sizes were of wrought iron, connected by inside collars and countersunk screws. A length of 150 feet of each was put in, but the actual depth drilled was only 77 feet with the 23-inch crown, and 97 feet and 106 feet, with the 20½-inch and 18-inch crowns respectively. The tubes occasionally followed the next size drill for some distance, though a hard bed of rock generally prevented any further movement; hence the necessity of longer lengths of tubes over the distance drilled. In the case of the 21-inch tubes they followed into the next size drilled six months after they had been put down. The bottom pipe of each set of tubes was provided with a steel-edged shoe to facilitate its progress.

The tubes were jointed together as they were lowered into the bore-hole, the whole length of 150 feet was then lowered by means of a "bayonet joint" fixed to the end of the rods. This tool was an iron ring or plate having two projections on the outside rim opposite to each other, and which fitted into channels in the inside of the top pipe of each length of tubes. Upon reaching the bottom one half turn in the reverse direction caused it to part from the tubes, leaving them in position.

The 15¼-inch crown having drilled through only 70 feet when the bottom of the clay was reached, it was resolved to force the 17-inch tubes down to the harder beds below the clay, rather than use another length of tubes and so reduce the size of the hole. To accomplish this the tubes were grappled and forced down, but the several bands of limestone at the base of the lower lias clay prevented them from going within 30 feet of the required position. In order to remove these bands of rock undercutting was adopted.

The machine used consisted of a tube 3 feet in length, 15 inches in diameter, and attached to the core-tube. On the sides of this tube, and projecting inwards, were three cylinders 6 inches in diameter; in each cylinder was a piston held in the tube by a spring, to allow a free passage; but upon its arrival below the pipes, water pumped down the rods forced out the pistons. At the end of each of these were steel cutters set with diamonds which, as the tool was worked upwards, cut away the rock below the pipes. This tool succeeded for some time; but several of the diamonds were lost, and ultimately the entire length of the 17-inch tubes was drawn to the surface, and the hole trimmed down with the larger crown. The pipes, when again lowered, rested upon the hard beds at a depth of 738 feet.

Progress of the Boring.

The boring was commenced in the Lias clays, which extended to a depth of 738 feet from the surface. The average rate of progress, including boring and extracting, was about 6 feet per day of twelve hours, a large portion of the time being occupied in lowering and raising the tools.

Below the Lias, instead of the triassic beds, a series of abnormal conglomerates, sandstones, and marls were met with, resting upon a hard quartzite rock. The progress in the hard beds, with the exception of the quartzite, was very good; upon one occasion a depth of more than 4 feet having been drilled within the hour. These beds were 67 feet 6 inches in thickness, and were reported by Mr. Etheridge to have no equivalents in Britain, no series being like them; and in the absence of all fossil remains it was doubtful to what geological age they belonged.

The hard quartzite found immediately below these rocks was 25 feet in thickness, and presented a weathered or eroded surface passing gradually and conformally into a sandstone, below which the Mountain Limestone of the Carboniferous period with its numerous fossils was reached. The progress in the quartzite was 20 inches per day; on account of its fissured structure this rock was difficult to bore. Many diamonds were lost, and one crown was worn out; and, through the irregular working, the rods were broken five times during the drilling through 25 feet.

When in this quartzite some pieces of broken iron got into the bore-hole, and to extract these the bottom was broken up by jumping with a heavy chisel, and the *débris* removed by a shell; the progress by this jumping was at the rate of 3 inches per day.

The Carboniferous Limestone was 14 feet in thickness, below which were yellow shales containing fossil plants. When the shales were reached the Directors of the water-company felt compelled to stop all further boring. Although it was possible that a fissure might be struck, containing water, in beds of limestone, alternating with the shales, it was considered improbable, and the depth to which the boring might have to be carried before reaching such a fissure was very uncertain.

The trias was proved to be absent, or it might be represented by the few feet of abnormal strata between the lias and the quartzite, and it was evident that the "Water Stones" were altogether absent.

The following was the succession of strata passed through in the two wells and in boring; surface 278 feet above sea-level:

	Feet.	Inches.
Surface soil	4	0
Lias clays	734	0
Various conglomerates	27	0
Green and light sandstones	23	6
Green marly sandstone	3	0
Brown sandstone	6	6
Brown marl	3	0
Fine grained conglomerate	2	6
Marly sandstone, with blocks of quartzite	2	0
Hard quartzite rock	25	0
Mountain limestone	13	6
Yellow shale	4	0
	848	0

In the Appendix, Table I. gives the statistics of the boring through the different strata at Kettering Road, with the several sizes of crowns; while Table II. contains the results obtained from a boring at Gayton, 5 miles south-west of Northampton, which is still proceeding.

Delays.

The progress of the boring was much hindered by accidents and delays. The most numerous of these were caused by the breakage of the rods, the place of fracture usually being the collar, though in some cases the thread of the rods was stripped. When boring in the clay seven collars were broken, and in the quartzite five; in clearing out sediment, on account of the fragments of the rock and small stones which had fallen from the sides, five collars were broken; two were also broken when extracting the core. To make the connection again when such an accident happened, the upper length of rods was drawn to the surface, and a bell-tap (Fig. 7) attached, lowered, and revolved over the rods left standing in the hole; a screw was thus cut on the broken end of the rods, to which the bell-tap was firmly attached, and the whole of the rods drawn to the surface, and the broken collar replaced by a new one. Two kinds of taps were used for this purpose; one a bell-tap for lowering over the rods, the other a taper-tap (Fig. 6) for insertion in the hollow of the rods. Upon one occasion, in recovering the rods which had been broken, a second collar broke, the tap at the time being in the hole; fortunately this second breakage occurred in the 24-inch pipes, and in this case the water was withdrawn and a man lowered, who made the connection. The time occupied

in repairing such accidents varied from an hour or two, to sometimes more than a day.

Several times during the operation of boring small pieces of iron getting into the hole necessitated the stoppage of work to extract them. These pieces had broken from the top of the 22½-inch cast-iron lining tubes. In lowering the tubes they broke away from the bayonet-joint and fell a distance of 480 feet to their position at the bottom of the hole. The tubes, which weighed upwards of 10 tons, passed through a bed of 50 feet of accumulated sediment. In raising and lowering the tools they caught against the ragged top of the tube where it had broken from the bayonet-joint, and thus fragments were broken off which fell to the bottom. These pieces of iron, when drilling in the clay, were, in the majority of cases, forced into the sides of the bore-hole; but in drawing the 17-inch tubes to enlarge the hole, the sides falling in carried the fragments of iron with them, which in the harder beds became a source of great trouble. In the clay a wedge-shaped tool was used to cut a hollow in the bottom of the hole, and at the same time sweep the small pieces of iron into it; the crown was then lowered and a length of core drilled and extracted, and the iron brought to the surface in the hollow on the top of the core. In the harder beds, where this tool would not work, a heavy chisel was used, and the hole was "jumped," the sediment, with the iron, being extracted by a shell. Some of the iron was extracted by a plug of wood, which fitted into the core-tube, being forced several times upon the bottom, causing numerous pieces to adhere to it.

The core-tube sometimes became clogged in the hole; in this case the lifting-chain was removed from the framework and replaced by a hempen rope 6 inches in diameter, reefed four times through blocks and attached to the windlass. By using this rope and blocks a more elastic and greater strain could be exerted; but the rope was more than once broken before the core-tube could be moved.

Testing the Water.

In the beds above the hard quartzite a small supply of water had been met with. This was noticed by the water in the pipes rapidly falling to a depth of 130 feet from the surface.

Water was drawn from the pipes by a shell, and the rise carefully noted; upon the first trial it was observed to be coming in at the rate of 525 gallons per hour, and at the second trial at 537 gallons per hour.

This was not taken much notice of at the time; but afterwards,

when the carboniferous shale had been reached, and before abandoning the boring, it was resolved to test the inflow of water with a pump, as it was considered probable that by so doing such a pressure would be laid upon the opening as to increase the yield.

For this purpose a temporary pump was arranged in the bore-hole. The barrel, 6 feet in length and 15½ inches in internal diameter, was suspended in the bore-hole by two steel wire-ropes; the rising main from the barrel to the surface was made up of a length of 190 feet of 18¾-inch, and 60 feet of 20-inch tubes. The pump-bucket was attached by boring-rods to a rocking beam on the surface, the opposite end of which was loaded with several tons of pig-iron to counterbalance the weight of the column of water which the bucket would have to lift. This beam was worked by a system of tooth-wheels, the motive power being obtained from the portable engine used to drive the boring machinery.

Pumping was carried on continuously for seventy-seven hours at 3½ to 4 strokes per minute, raising about 5,000 gallons of water per hour. The water-level rapidly sank, and frequent stoppages had to be made to allow the water to rise above the suction-pipe, 30 feet below the pump-barrel, or 280 feet below the surface.

After pumping a short time the water was found to be salt. This was not noticed in the first instance, owing to the fresh water pumped in during the boring. The specific gravity of the water was 1·12, the temperature being about 70° Fahrenheit; it contained about 20 lbs. of mineral matter to the 100 gallons. This was evidently the water expected to be met with, as a saline spring had been found in sinking the shaft before mentioned, at Kingsthorpe, 2 miles to the north of the town. This spring might have been stopped out had a deeper supply of water been met with.

On account of the large size of the rising-main in the bore-hole, it was impossible to gauge the rise and fall of the water during the pumping by the ordinary method of float and line. To overcome this difficulty a tube, ⅜ inch in diameter and 210 feet in length, was lowered between the rising main and the side of the bore-pipes; the end at the surface was connected to an air-pump with pressure-gauge, while the other end dipped under the water. Air was then pumped into the tube until it escaped through the end under water; the pressure on the gauge indicating the depth or head of water above the bottom of the pipe. When the lifting-pump was worked, and the level of the water was lowered in the

bore-pipe, the hand of the pressure-gauge indicated the gradual lowering of the head of water. By this indication, and knowing what quantity of water the pump was throwing, the inflow of water could be ascertained. For example, supposing a pressure of 20 lbs. was registered on the gauge, that, at that particular moment, being the pressure required to force air through the tube against the head of water above the bottom of it; then, allowing 2·3 feet for every lb. pressure, $20 \times 2 \cdot 3 = 46$ feet; and the depth of the bottom of the tube being known, say 210 feet, $210 - 46 = 164$ feet, the distance from the surface to the water.

Before finally abandoning the undertaking, as many of the lining tubes as possible were recovered. For this purpose a prong grapnell was fitted under the ribs and stays in the wrought-iron tubes. Heavy clams were then bolted to the rods, and, by means of two hydraulic jacks, the tubes were moved from their position and raised by the lifting chain. All the 17-inch tubes were recovered; the 20-inch tubes parted in the middle, and the upper part only was recovered. Most of the 24-inch tubes were drawn from the well. The hole was then securely plugged and filled in for some distance, to prevent the salt water from rising into the upper pervious strata, and so contaminating the present water-bearing beds.

The time occupied in the different operations connected with this boring, from April 1879 to February 1881, was as follows:—

	Days.
Opening, cleaning out, and retimbering part of 10-feet well	48
Sinking 5-feet shaft for 200 feet	104
Fixing boring pipes	25
Boring 448 feet	96
Fixing two sets of lining tubes	33
Delayed by accidents	85
Testing water	67
Fixing machinery, and various works	132
Total	590

The work was carried out under the superintendence of Mr. Maurice Belsham, on the part of the contractors; the Author being present during the whole of the operations, in the interests of the water-company.

The Author desires to tender his best thanks to Messrs. T. Doowra and Son and Mr. J. K. Gulland, for placing the drawings of their boring-machinery at his disposal.

The Paper is accompanied by three sheets of tracings, from which Plate 16 has been prepared.

APPENDIX.

TABLE I.—BORING at KETTERING ROAD, NORTHAMPTON, 1880.

Diameter of Crown.	Depth Drilled.	Number of Days Drilling and Extracting.	Average Depth per Day.		Nature of the Strata.	Diameter of Core.	Quantity of Material Extracted.
Inches.	Feet.		Feet.	Ins.		Inches.	Per cent.
23	77	17	4	6½	Lias clay . . .	19¼	..
20½	97	15	6	5½	„ . . .	16¾	..
18	106	16	6	7½	„ . . .	14½	..
15¾	55	11	5	0	„ . . .	12¼	..
„	68	10	6	9	Sandstones and marls	„	95
„	25	15	1	8	Quartzite . . .	„	100
„	20	5	4	0	Limestone and shale	„	98

TABLE II.—BORING at GAYTON, SOUTH-WEST OF NORTHAMPTON, 1882.

Diameter of Crown.	Depth Drilled.	Number of Days Drilling and Extracting.	Number of Hours Drilling.	Average Depth.				Nature of the Strata.	Diameter of Core.	Quantity of Material Extracted.
				Per Day.		Per Hour.				
Inches.	Feet.			Ft.	Ins.	Ft.	Ins.		Inches.	Per cent.
18	125	11	104	11	4	1	3	Lias clay . . .	14½	88
15¾	148	13	127	11	4½	1	2	„ . . .	12¼	90
13⅝	182	17	183	10	8½	1	0	„ . . .	10¾	92
11⅞	117	10	100	11	8	1	2	„ . . .	9¼	88
„	63	8	60	8	0	1	0½	Red marl and sandstone	„	64
10⅛	215	25	213	8	7	1	0	Lower carboniferous Limestone and shale	7¾	84
								Sandstones . . .	„	68

OBITUARY NOTICES.

WILLIAM SPOTTISWOODE, M.A., LL.D., Pres. R.S., son of Andrew Spottiswoode, the printer, was born in London on the 11th of January, 1825. He belonged to an old Scottish family, many members of which achieved distinction. He was educated successively at a school at Laleham, at Eton, and at Harrow where he remained three years; whence, in 1842, he proceeded to Balliol College, Oxford, and in 1845 gained a first class in mathematics. Although on quitting college he undertook the active management of the business of the Queen's printers, which he never relinquished, the bent of his mind led mainly to the cultivation of mathematics and physics. His earliest work appeared in the shape of five quarto pamphlets, with the title "Meditationes Analyticæ," 1847. His subsequent numerous original mathematical investigations, in the "Philosophical Magazine," "Cambridge and Dublin Mathematical Journal," "Quarterly Journal of Mathematics," and many other scientific periodicals, gave him a world-wide reputation. In the field of physics his researches on the "Polarization of Light" may be mentioned. One of the chief factors in raising him to so high a position in science was his exceptional qualifications as an organizer. He was Treasurer of the British Association from 1861 to 1874, of the Royal Institution from 1865 to 1873, and of the Royal Society from 1871 to 1878. He was chosen Honorary Secretary to the Royal Institution in 1871; was President of the London Mathematical Society, 1870 to 1872, and of the British Association 1878; and was elected Correspondent of the Institut of the Académie des Sciences in 1876. He was elected an Honorary Member of this Institution on the 6th of March, 1883, because, in the words of the nomination paper, "By his attainments as a mathematician—as evidenced by numerous Papers presented to the Royal, the Royal Astronomical, and other scientific societies, and by his position as President of the Royal Society of London since the 30th of November, 1878—he has materially aided the progress of some of those sciences on which the practice of Civil Engineering

chiefly depends." He died on the 27th of June following, after an illness of three weeks, from typhoid fever.[1]

VALENTINE BROWNE, son of Captain Valentine Browne, formerly paymaster of pensioners at Shrewsbury, was born in 1824, being of Irish descent. He was educated at Elphin, Co. Leitrim, and at Cheltenham College, England, and was then articled to Mr. Hall, County Surveyor of Leitrim, with whom he remained seven years. He was afterwards engaged for a short time under Sir John Macneill, M. Inst. C.E., and was next employed for two years, as District Engineer under Valentine Browne, for the Board of Public Works, Ireland. He subsequently became Resident Engineer on the Frankfort, Wiesbaden, and Cologne Railway, under Mr. Vignoles, Past President Inst. C.E.; and six months later, in 1857, was appointed assistant to Mr. G. M. Miller, M. Inst. C.E., in the permanent way department on the Great Southern and Western (Ireland) Railway, and became Engineer to the northern section of that line in 1865. He carried out several works, such as renewing in stone and iron some large river bridges originally constructed of timber, and was joint engineer with Mr. William Baker, M. Inst. C.E., for the construction of the branch line from Kingsbridge to the North Wall, which passes round the north side of Dublin. Mr. Browne was elected a Member of the Institution on the 4th of May, 1869. He left the Great Southern and Western Railway in 1877, and died at Tuam on the 6th of January, 1883.

ROBERT DAGLISH, third son of the late Mr. Robert Daglish, M. Inst. C.E.,[2] was born in Wigan, Lancashire, in the year 1809. He served an apprenticeship to the firm of Messrs. Hick and Rothwell, of Bolton-le-Moors, and applied himself so assiduously to obtain a thorough practical knowledge, that whilst still an apprentice, he was sent to assist in the erection of a large pumping-engine and pumps in the shaft of the Haydock Colliery, looked upon at that time as a superior class of mining machinery, and which to the present day is doing good work. In 1830

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[1] Fuller details of the life of Mr. Spottiswoode are given in "Nature," 26th April, 1883.

[2] Minutes of Proceedings Inst. C.E., vol. xxvi., p. 561.

Mr. Daglish joined the firm of Messrs. Lee, Watson & Co., iron founders, St. Helens, in which business his father had also an interest. The works then only covered about 5,000 square yards, but new fitting and turning shops, smithery, with pattern shop over it, were soon afterwards built. In the year 1832 an engine and machinery were erected for working the inclined planes of the St. Helens and Runcorn Gap Railway. In 1837–8 Mr. Daglish entered into a contract for the erection of the engines, boiler, and machinery, for the manufacture of plate glass at the works of the Birmingham Plate-Glass Works, Smethwick, near Birmingham, as well as the Plate-Glass Works, Sutton, St. Helens.

About 1839 Mr. Daglish, in conjunction with Mr. John Smith, undertook to work the traffic of the then St. Helens and Runcorn Gap Railway, and continued to do so until 1848, having a separate establishment, called Sutton Sheds, St. Helens Junction, for keeping in repair the engines and rolling stock. In 1845 Mr. Daglish erected his first cotton-mill engines at Wigan. About 1846 he was engaged in large contracts for bridges required on the Liverpool and Bury Line of the Lancashire and Yorkshire Railway, including two large lattice-bridges, for carrying the railway over the river and canal at Bolton. In 1847 the Wavertree road-bridge, Edge Hill, Liverpool, was erected by the then firm of Robert Daglish, Jun., & Co. In 1849 the same firm built the Great Howard Street and Borough Gaol bridges of the Lancashire and Yorkshire Railway, Liverpool. In 1850 Mr. Daglish, in partnership with the late Mr. McCormick, constructed the Preston Extension of the East Lancashire Railway, including a large bridge over the River Ribble. From 1851 the foundry business was conducted by Mr. Daglish alone until 1869, when he took his nephew, Mr. George H. Daglish, M. Inst. C.E., into partnership, and which partnership was carried on until his death on the 6th of May 1883. Mr. Daglish supplied many waterworks pumping-engines, amongst which are those for St. Helens, Newark, Southport, Wirral, near Birkenhead, Bristol, Hodbarrow Mines, Widnes, and Warrington. In 1852 the coal-drops at Garston, near Liverpool, were erected. In 1856 Mr. Daglish constructed the Barrack or Bloody Bridge over the Liffey at Dublin. In this year the St. Helens works had to be further extended, and from 1863 to 1882 the works were very much improved and enlarged, so that they now cover an area of about 22,400 square yards.

Mr. Daglish was elected an Associate of the Institution in 1852, and became a Member by transfer in 1874. He was a Director of

the St. Helens Canal and Railway Company from 1854 to 1864, and of the Lancashire and Yorkshire Railway Company from 1876 to 1883. He was also on the Commission of the Peace for the counties of Lancashire and of Cheshire.

JAMES EDWARD McCONNELL was born on the 1st of January, 1815, at Fermoy, Co. Cork, where his father, Mr. Quentin McConnell, possessed a fairly prosperous business in large iron-works. He was left fatherless at the age of four, and came under the care of his uncle, Mr. Alexander McConnell, then resident in Ayr, where he spent most of his early years; till, owing to a difference with his uncle, he was launched on the world with a capital of ten shillings.

He first obtained employment in the works of Messrs. Girdwood and Co., of Glasgow, where he was regarded as a steady reliable workman, assisting the foremen and managers against the frequent difficulties arising in those days through trades-unions and strikes. Later on he was engaged in the works of Messrs. Vernon and Co., of Liverpool, as foreman, and while there superintended the erection of several horticultural buildings, and a great deal of machinery for the late Earl of Clare at Mountshannon.

In 1842, on the recommendation of Messrs. Bury, Curtis and Kennedy, Liverpool, he was appointed Locomotive Engineer of the Bristol and Birmingham Railway. On the 15th of February, 1847, he was made Locomotive Superintendent of the southern division of the London and North Western Railway, which post he held for fifteen years. His patents, in 1853, of "Improvements in Locomotive Engines" and of "Hollow Railway Axles" were decidedly successful. During the latter part of his connection with the London and North Western Railway, he worked with his engines the main line from London to Stafford and all its branches. On his resignation, in 1862, he received from the officials and employés a handsome service of plate, together with a flattering address.

At that time he bought an estate near the village of Great Missenden, and several commercial enterprises under his hands became great successes. He now took an office at Westminster, and commenced to practise as a mechanical engineer. He was largely engaged in the valuation of railway rolling stock, and in the assessment of railway property. In 1871 he entered into partnership with Mr. W. Marshall of Norfolk Street, Strand, for

a period of ten years. They valued this class of property for upwards of one hundred of the Union Assessment Committees.

In 1870 he was appointed a magistrate for Bucks, and in 1873 he filled the office of High Sheriff. He was one of the founders of the Institution of Mechanical Engineers. In 1862 he was on the Jury for railways in the International Exhibition; and in 1867 he was selected to represent the British Goverment in the interest of English railways at the Paris Exhibition.

Mr. McConnell was one of the oldest members of the Reform Club. He was greatly esteemed in private as well as in public life. He was elected an Associate of the Institution on the 11th of March, 1845, and became a Member by transfer on the 4th of February, 1851. He died on the 11th of June, 1883, after an illness of about a fortnight, of pulmonary congestion.

JOHN MILLER was born at Ayr, on the 26th of July, 1805. His father, Mr. James Miller, was a builder in that town, and it was probably from seeing his father engaged in the construction of some of the principal buildings in Ayr and the neighbourhood that Mr. Miller first acquired the desire of following the profession of a Civil Engineer. He received the elementary part of his education at Ayr Academy, and at the age of twelve and a half years he entered the office of Mr. C. D. Gairdner, solicitor, factor for the Earl of Cassillis, and other landed proprietors in the county. Mr. Miller, however, evinced no liking for the legal profession, although he always admitted that the knowledge he obtained of county matters, and the management of estates, while in Mr. Gairdner's office was of great service to him in after-life. During this time Mr. Miller devoted his evenings to the study of mathematics under a private teacher. At the end of five years Mr. Gairdner became agent for a bank, and gave up the legal profession, and Mr. Miller determined to become a land surveyor, the professon of civil engineer being then almost unknown in Ayr. In 1823 he left Ayr for Edinburgh, and entered the office of the late Mr. Thomas Grainger,[1] M. Inst. C.E., and so steadily did he apply himself to work that in 1825 Mr. Grainger took him into partnership.

By this time the importance of railways had begun to be recognised in Scotland; and in 1823 Mr. Grainger was employed to lay out a line to connect the Monkland mineral field with the Forth

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[1] Minutes of Proceedings Inst. C.E., vol. xii., p. 159.

and Clyde Canal at Kirkintilloch, which line was carried out by Mr. Grainger, as also the extension of the line to Ballochney and the Wishaw and Coltness line. The chief promoters of these first railways in Scotland were the Forth and Clyde Canal proprietors, and they, in the year 1825, projected a scheme for the construction of a line of railway between Edinburgh and Glasgow. Mr. James Jardine was appointed Engineer, and he entrusted the survey of the western half of the line to Mr. Miller. This scheme, however, was not carried out. The line so proposed followed very much the same course as is now taken by the Caledonian Company's direct line between Edinburgh and Glasgow. As then proposed it was only intended for the conveyance of minerals and heavy goods traffic, passenger traffic not being thought of. From 1829 to 1831 Mr. Miller was engaged in laying out and constructing roads in various counties in Scotland and in the south of Ireland; but after this date nearly his whole time was devoted to railway engineering. In 1830 the project of a railway between Edinburgh and Glasgow was revived, and Messrs. Grainger and Miller were appointed engineers. Like the project of 1825, however, this scheme also failed. It followed generally the route now taken by the line between Edinburgh and Glasgow *viâ* Bathgate and Airdrie.

From this time, although Mr. Grainger and Mr. Miller continued in partnership until 1845, they acted separately in all railway matters, each taking the exclusive charge of laying out and executing the works with which each was specially entrusted.

In 1831 the Glasgow and Garnkirk line was opened for passenger and goods' traffic, and this gave a fresh impetus to the construction of railways in Scotland. In this year Mr. Miller was again engaged laying out the Edinburgh and Glasgow line, and, having completed the survey, the late Mr. George Stephenson was asked to go over the line with Mr. Miller and report on it. His report was so favourable that, in 1832, a bill for its construction was introduced into Parliament; but was very summarily rejected on the opposition of the landowners, who were then, as a rule, greatly opposed to having their estates intersected by railways.

In 1835 Mr. Miller was Engineer for the Dundee and Arbroath Railway, the Glasgow, Ayr and Kilmarnock Railway, the Edinburgh and Glasgow Railway, now forming part of the North British system, and several others which were not proceeded with. The works on the above-named lines were all designed and carried out by Mr. Miller. He was subsequently Engineer for, and constructed, the North British Railway, Edinburgh to Berwick, and

branches, the Edinburgh and Hawick Railway and branches, now part of the North British line; the Dundee and Perth Railway, now part of the Caledonian system; the extension of the Glasgow, Ayr and Kilmarnock Railway to Dumfries and Gretna, now the Glasgow and South Western Railway; the Stirling and Dunfermline Railway, and other lines; and in 1845 he was appointed Engineer by the promoters of the Direct Northern Railway extending from London to York. That the line so laid out between London and York merited the name of "Direct" may be inferred from the fact that the distance between London and York by it was 176 miles, while the distance as the crow flies between St. Paul's in London and the great tower of York Minster is 174¼ miles. An arrangement was subsequently come to between the rival schemes of the London and York, and Direct Northern Companies which resulted in the present Great Northern line, and Mr. Miller was appointed Engineer for the construction of the works of the Northern half, an appointment which he subsequently resigned. Mr. Miller was also Engineer for many other lines both in England and in Scotland, some of which were not proceeded with at the time, but have since been constructed. In November 1845 he deposited plans for upwards of 1,500 miles of railway.

On the above railways there are probably some of the finest viaducts in Great Britain; notably the Almond Valley Viaduct on the Edinburgh and Glasgow line, consisting of forty-six arches of 50-feet span; the Avon Viaduct on the same line of twenty-one arches of 50-feet span; the viaduct over the canal near Falkirk, and the Castlecary Viaduct on the same line. The Dunglass Viaduct on the North British line between Edinburgh and Berwick, the centre arch of which has a span of 135 feet; Ballochmyle Viaduct over the River Ayr, on the Glasgow and South Western line, the centre arch of which has a span of 180 feet, the level of the rails being about 170 feet above the river; and the Lugar Viaduct on the same railway, over the River Lugar, which consists of nine arches of 50-feet span, and five of 30-feet span, the rails being 150 feet above the river. Mr. Miller always considered the last-mentioned his greatest work. The foundations, owing to the old coal-workings underneath, gave great trouble, but the viaduct stands without the slightest flaw. The piers are 7 feet thick at their springing, and from their great height the viaduct has altogether a beautiful and light appearance.

Mr. Miller retired from the profession of Civil Engineer in 1850, and from that time seldom appeared as a witness in Parliament,

and then only in reference to schemes with which he had formerly been connected. In 1868 he was returned to Parliament as one of the members for the City of Edinburgh, but lost his seat at the General Election in 1874. Having on his retirement from the profession of Civil Engineer purchased the estates of Leithenhopes in Peeblesshire and Drumlithie in Kincardineshire, he devoted a great part of his time to the management and improvement of these estates. He died on the 8th of May, 1883, in his seventy-eighth year.

Mr. Miller was elected an Associate of the Institution of Civil Engineers in June 1830, and was transferred Member in May 1832. At the time of his death he was the senior Member of the Institution. He was also for many years a Member of the Royal Society of Edinburgh.

EDWARD FRANCIS MURRAY, born in Belfast in May 1818, was the second son of Sir James Murray, M.D. He received his early education at the Royal Academical Institute, Belfast, and in 1834 proceeded to France and Italy, where he pursued the study of architecture and drawing till the year 1836. On his return to England he became the pupil of Mr. Thomas Jackson Woodhouse, Civil Engineer, and was engaged with him in many surveying and engineering works in the north of Ireland, and in England on the Midland Counties Railway.

At the expiration of his pupilage with Mr. Woodhouse, he was introduced to the late Mr. I. K. Brunel, V.P., and was appointed one of his assistant engineers, being engaged for three years at the Box Tunnel, till 1842, when he went with Mr. Brunel to North Italy to lay out a line of railway through the Apennines between Genoa and Alessandria. This resulted in a survey being made for a railway to Turin and Milan. The line was ultimately carried out by the Sardinian Government, and in 1845 and 1846 Mr. Murray was engaged as an assistant engineer at the commencement of the works at the Giovi Tunnel and Genoa end of the railway.

He was afterwards, for a period of thirteen years, Assistant Engineer on the West Cornwall Railway, and Resident Engineer on the Windsor, Wycombe, Henley, and Uxbridge Branch Railways, and on the Brentford Railway and Dock.

After the death of Mr. Brunel in 1859, he was appointed Engineer-in-chief of the Wycombe and the Brentford Railway Companies. He was elected a Member of the Institution on

the 3rd of April, 1860. He constructed the road bridges across the Thames at Pangbourne, Walton, and Hampton Court, and continued in the exercise of his profession till 1864, when he retired into private life. He took up his residence in Ireland on his father's death in 1871. His own death was caused by a fall from his horse at Bray, Co. Wicklow, on the 27th of September, 1882.

JOHN PATON was the only son of Mr. James Paton, of Dumfries, and was educated at the Universities of Glasgow and Edinburgh. He served an apprenticeship of seven years under Mr. John Wilson, Assoc. Inst. C.E., an extensive iron and coal master at Dandyvan, and was then for eight years colliery agent, and furnace and forge and mill manager, and ultimately general manager of the Silverdale and Biddulph Valley Works, near Stoke-upon-Trent. Leaving this, he, for two and a half years, held the position of consulting manager of the iron department of Sir John Brown and Co.'s works, Sheffield. In February, 1863, he became general manager and engineer to the Blaenavon Iron and Coal Company. Through his instrumentality the town of Blaenavon was greatly enlarged and its resources developed, and the works under his management were much improved. It was through him that one of the largest furnaces in South Wales was constructed at Blaenavon. On retiring, in 1874, he went to live at Pontypool, where he died suddenly of apoplexy on the 30th of June, 1883. Mr. Paton was elected a Member of the Institution on the 7th of April, 1868.

THOMAS ROBERT WINDER was born at Gate-beck, Westmoreland, in 1817, and was educated successively at Prestonpatrick and Kirkland. He served an apprenticeship of five years, 1834–39, in the works of Messrs. Thomas Winder and Co., at Low Mill, Westmoreland, principally occupied in the application of water as a motive power, and partly under Mr. Perry, when surveying the country between Lancaster and Carlisle for railway promotion, and in the construction of a section of the Lancaster and Preston Railway, after which he assisted in laying out the railway through Wakefield. He next for many years had responsible charge for the contractors of the execution of extensive works on portions of the Great Western Railway in 1839–43; the Eastern Counties in

1843–45; the Southampton and Dorchester in 1845–47; the East Anglian and the North London Railways, and the Plymouth Great Western Dock in 1847–50; the Wolverhampton Railway in 1850–52; the entrance to the West India Docks in 1852–53; a railway bridge over the Medway, and a quay at Rochester, in 1854–56; and the Admiralty Pier Works at Dover in 1856–59. He was also employed, in 1853–54, as Engineer, in conjunction with Sir John Rennie, to the Netherlands Land Reclamation Co., and at a later date as Engineer for Rye Harbour. Subsequently he was engaged in making surveys and estimates in Malta, Sicily, Holland, and Cornwall. Here he carried out, from his own designs, the Harbour and Dock Works at the port of Pentewan. At the time of his death, on the 11th of October, 1882, he had been Resident Engineer for eight years, under Mr. J. Fowler, Past-President Inst. C.E., and the late Mr. R. J. Ward, M. Inst. C.E., on the Rosslare Harbour Works, and the Waterford and Wexford Railway, the latter of which was just completed. Mr. Winder was a man of mature experience, upright, and conscientious, and always took great pains to explain in detail to those by whom he was employed everything relating to the work under his charge, and he combined with a thorough knowledge of his profession as a Civil Engineer, the very valuable qualification of keeping clear accounts.

RICHARD FRANCIS ALFORD, the eldest son of Mr. Richard Alford, F.R.C.S., was born on the 8th of May, 1849, at Tewkesbury, in Gloucestershire. He was educated first at the Engineering College, Chester, and then became a pupil of Mr. E. Slaughter, M. Inst. C.E., from October 1865 to May 1870, at the Avonside Engine Works, Bristol, partly in the shops and partly in the drawing-office. He remained with Mr. Slaughter some time after his pupilage was over; but, his health failing, he took a voyage to the West Indies. After his return he was engaged on various works, from May 1871 till the end of 1872; and in January 1873 he was again employed at the Avonside works, on some Fell engines for New Zealand, on Fairlie engines, and various other works. From November 1878 until his death he was in the office of Messrs. Hemans, Falkiner, and Tancred, at Westminster.

He was elected an Associate-Member of the Institution on the 6th of April, 1880. Mr. Alford had been delicate from infancy, and at the age of eighteen had an attack of pleurisy, from the

effects of which he never fully recovered. He died rather suddenly, on the 9th of December, 1882, from the bursting of an abscess on the brain.

HENRY AUGUSTUS SEVERN, the second son of Mr. Joseph Severn, H.B.M. Consul at Rome, the intimate friend of Keats, was born on the 21st of June, 1833, in the Via Rasella, Rome. Mr. Severn was educated at Westminster, and at an early age exhibited singular aptitude for chemical and mechanical pursuits. But in those days the appliances necessary for the young student to prosecute his researches were too costly for him to think of purchasing them, so he literally had to make his own apparatus, and he took pleasure in relating to the young people about him, how he had bought a bit of copper here, and other unconsidered trifles there, to make something he had seen but could not afford to buy; how and why he had failed, and so on. The result of this rude early experience was that, later in life, he seemed never to be at a loss, because if the appliances wanted for any special object were not to be had, and this often happened in the early Colonial days, he always found materials wherewith to make them. After serving three years' pupilage, 1848-51, in Messrs. Fanham's works, in Manchester, he joined Professor Lewis of Westminster, and in April, 1853, was employed at the London Mint. He left England in 1854 for Sydney, New South Wales, where he accepted the appointment of Assayer to the Sydney Mint, and remained there until the Melbourne Mint was established. At that time the Union Bank of Australia found it necessary to have an assayer, and the post was offered to and accepted by Mr. Severn. Heavy as his duties were, he not only kept abreast of the rapid progress then being made in natural science, but also studied civil engineering, especially that branch pertaining to gold-mining, and the treatment of auriferous quartz. After remaining six years in the position above-named, he accepted that of Manager of the Caledonian Mine, at that time the richest in the Thames gold fields in the northern part of New Zealand. The enormous yield of this mine is well known, and the quantity of amalgam was so large that it could with difficulty be treated in the usual way, and this led to the use of the simple apparatus known as "Severn's Amalgam Squeezer," which does as much work in an hour as can be done by the old process in a day. When the Caledonian mine became exhausted, he accepted the assayership of the Bank of New

Zealand, at Grahamstown (Thames Gold Fields). Whilst here he constructed a reflecting telescope 12 feet long, with 13 inches aperture, for observing the transit of Venus in 1873. He subsequently delivered lectures on scientific subjects in some of the principal places in the Colonies. These lectures were attended by upwards of 60,000 persons, a very large number, considering the then sparse population, creditable alike to the lecturer and to the Colonists.

Mr. Severn returned to England in 1880, and was elected an Associate Member of the Institution on the 7th of December in that year. Soon after his arrival he was appointed Engineer-in-chief to the Indian Gold Mines. Since then he resided principally at this Company's mines near Devála in the Wynaad, where he personally superintended the execution of the works which he had designed. He was an indefatigable worker, but in his anxiety that the mines should be in every sense successful, he exposed himself unduly, and died of brain fever on the 18th of April, 1883, at his bungalow near the mines.

HENRY LEE CORLETT, son of Mr. Henry Corlett, was born in Dublin on the 27th of June, 1826. Here he was educated, and was subsequently articled to Messrs. John Hutton and Sons, who were at that time (1845) engaged in the manufacture of railway rolling-stock. Mr. Corlett had already shown great ability in mechanical construction, and as a draughtsman remarkable capacity, and took steps to prepare for entrance to the engineering school of Trinity College. He now sought and obtained the appointment of Superintendent of railway-carriage rolling stock on the Great Northern (Ireland) line at Drogheda. About 1850 Mr. Corlett was transferred to the Inchicore works of the Great Southern and Western Railway, where he remained till 1877. Mr. Corlett introduced many improvements in railway-machinery and appliances. In 1854 he took out a patent for springs for rolling-stock; in 1859 for improvements in permanent way; in 1862 for tuyeres; in 1867 for buffers; and in 1871 for hydraulic lifts for carriages. In 1877 he patented his buffing springs and cases. Mr. Corlett had also constructed a model for a railway post-office, from which the mail-bags could be mechanically discharged or received while the train continued in full motion. He was elected an Associate of the Institution on the 6th of March, 1860. On leaving Inchicore

Mr. Corlett settled in London, and having previously taken much interest in the tramway system in Dublin, where he had been director on the northern tram line, he turned his attention to the tram system in the metropolis, and became Chairman of the Southwark and Deptford, and the Woolwich Tram Companies. In 1880 his health began to fail, and he died on the 19th of April, 1883.

GEORGE WYTHES, son of the late Mr. Thomas Wythes, of Worcestershire, whose family for a long series of years had occupied land in that county, was born in June 1811. At an early period of his life he exhibited, in a very remarkable degree, some of those sterling qualities of character for which, in later years, he was so eminently distinguished. Few men afforded a more striking proof of the value and importance of self-reliance and self-respect, not only in building up a colossal fortune for himself, but, while doing so, in rendering signal and permanent benefit to the commercial activity and enterprise of the community in which he lived. His unflagging energy and perseverance, under more than ordinary difficulties, placed him in a comparatively brief period in the foremost rank of railway contractors. Gifted with extraordinary powers of perception, he possessed the rare and happy art of surrounding himself with men of zeal, efficiency, and willing service. He was a shrewd, intelligent man of the world, and was endowed with a keen sense of penetration into human character. Hence it is not surprising that he became one of the most popular, as he certainly was one of the most successful, railway contractors of his day. Such a man does not rise to the summit of his profession by accident. There is a shallow notion, and it is to be feared somewhat popular, that chance, or luck, aided by opportunity, decides the destiny of such men. There never was a greater mistake. Let any one examine with attention the mental and physical development of these successful pioneers in the engineering profession. Let him note the investment of brain and muscle which forms the stock-in-trade which these foremost men employ who do the world's work. He will soon perceive that chance, in its popular meaning, has nothing to do with the advancement of such men. Extraordinary powers of perception, combined with extraordinary perseverance, enable them to win the day, and to reach the goal which crowns all their efforts, with the justly-merited rewards of wealth and social distinction. This, and this alone, was the secret of the

success of Mr. George Wythes. His peculiar fitness for work soon opened up to him an enormous amount of business; so that, among the earliest efforts of his industry and skill, he was successfully engaged in a very large contract on the Essex line of railway. The following extract from a notice of his work is taken from the *Chelmsford Chronicle* of that date—April 1843:—

"The village of Kelvedon was all gaiety and bustle on the 29th ultimo, first, by the life and animation thrown into it, in common with other towns, by the opening of the line; and next, because G. Wythes, Esq., having completed his contracts in that district, set the day apart as a holiday for his workmen, and furnished them with the means of enjoying it in true English style. Never were cheers more enthusiastic or more honest than those which echoed to the health of their excellent master, so justly has he earned the good repute of the neighbourhood."

It is well known that, although only at that time in his thirty-second year, he had amassed a considerable sum of money, and there are engineers still living who can remember how he was pointed at as he passed along as the rising contractor of the day. After his success in the Essex line he rose rapidly in influence and in wealth in the railway world, until he became associated with Messrs. Brassey, Jackson, and others, in carrying out very important and extensive contracts in Europe and in the East. He undertook the early and more difficult part of the work of the Great Indian Peninsula Railway, from which he derived considerable profit. Still, it would be erroneous to conclude that he was always favoured with equal good fortune. It is well known that he met with many reverses, owing to the varying fluctuations of all such speculative undertakings. Nor was it only in railways that he realised his large fortune. At one period of his career he had a large interest in some blast furnaces in the north of England, and at the time of his death he was personally and financially interested in extensive mining operations near Spezzia. In fact, there are few countries in Europe with which his name and capital were not associated, and he had property scattered over almost every quarter of the globe.

Few men ever acquired greater influence among his employés, and, like his co-partner, Mr. Brassey, it was due mainly, if not exclusively, to the good sense and good nature which led him to treat every one connected with him in business, from the Navvy to the Engineer-in-chief, with that delicate and considerate courtesy which never yet failed to create mutual confidence and respect. There was another secret of his success which also appeared pro-

minently in Mr. Brassey's character. These men were always easy of access. No officials ever were allowed to be obstructives in the path of those who wanted a personal interview, regardless of the importance or position of the person seeking it, from the Plate-layer of the line of rails to the Chairman of the Company. If Mr. Wythes was disengaged and in his office the way was open to all comers. These small courtesies, in themselves, perhaps, mere nothings, are, in the aggregate, of the greatest importance. When a man in power and position assumes airs of authority, and stiffens his deportment with too much buckram and pipeclay, he may flatter himself that he commands obedience, but he may be very certain that he does not obtain respect. Along with these popular advantages which, like air-cushions, if they do nothing else, greatly assist in easing jolts, Mr. Wythes was a man of the utmost simplicity of character, in the ordinary details of everyday life, and he was as upright and sincere as he was simple. There is a very characteristic story told of those two great men. One day Mr. Brassey said to a friend of both, "Well, Wythes is a grand fellow. Do you know what he has done? I have just visited —— —— (who was laid up from chronic illness), and he told me that Wythes had been to see him, and said that he must not allow money matters to disturb his thoughts, for that he would take half his share of the loss in —— Railway." A short time after this Mr. Wythes said to the same friend, "Well, Brassey is a prince. Do you know what he has done? Why he has been to see —— ——, and he told him that he must not allow his mind to be worried in his illness about money matters, for that he would relieve him of half the losses. Isn't he a splendid fellow?" Now neither of these "splendid fellows" said a word about his having acted precisely as the other "splendid fellow" had done. They did the right thing, and in the right way. And when it is considered that this division of responsibility involved many thousands of pounds, some idea may be formed by the outer world of what sacrifices these railway princes were capable of making when the occasion required.

The subject of this memoir married Miss Frances Wagstaff in the year 1836, by whom he had an only son, born in 1839, and who died in 1875. This was a terrible blow to his father. Life lost its zest, and his home and wealth their charm. This crushing bereavement pressed heavily on his mind, and it is considered that it brought on that fatal malady which for eight years had been secretly undermining his constitution, naturally of the most robust description. He was a man of great reticence, even with his

intimate friends, and seldom, if ever, alluded to the depressing influences which all could see were telling their sad tale upon his health. The death of his wife occurred four years after that of his son. This completed the blank in his existence, and accelerated the ravages of the disease which now began to make serious inroads upon his bodily strength. He attended, it is true, to business with wonderful punctuality, and every Monday he visited his estate at Copt Hall in Essex. Still any one who knew him in former years, while his son still lived, could see that his life was disconsolate and purposeless. In the evening of his days he was bereft of all that could make life dear, and wrapped up in his own thoughts, in an inner world of sadness and disappointment he lingered on, always in physical weakness, and not unfrequently in pain. Death released him, in the seventy-second year of his age, from the solitariness of his sufferings, on the 3rd of March, 1883, at Bickley Hall, Kent.

Mr. Wythes was elected an Associate of the Institution of Civil Engineers on the 7th of February, 1865.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

The Application of Triangulation to the Survey of Towns.

By — GERKE.

(Zeitschrift des Architekten- und Ingenieur-Vereins zu Hannover, vol. xxix., 1883, pp. 304-306.)

In the summer of 1882, the Author had an opportunity of sharing in the completion of the triangulation of East Prussia, in which several sides were only partially observed, and in one triangle, not one of the angles was directly measured. The re-survey of the defective portions was ordered by General Bäyer, President of the Geodetic Institute, and was entrusted to Professor Fischer of Berlin. In carrying out this work, the following particulars are worthy of record: at one station, a scaffolding 56 feet high had to be erected, in which the post supporting the instrument had to be entirely detached from the observing platform, and it was noticed that under the action of the sun, this was daily deflected at an angle of about 10″ from the vertical axis. Heliotropes were employed for flashing signals, and a very interesting observation of the refraction of the rays of light consequent on varying densities of the atmospheric strata was made during the progress of this survey. The scaffolding or staging above-mentioned was just high enough to allow the heliotrope on it to be visible at another trignometrical station across an intervening forest; and it was observed, that in the suddenly bright sunshine after a heavy thunderstorm, the 56 feet high staging became visible (owing to refraction), for almost its entire height. Computing the coefficient of refraction in this case, under the assumption that a height of about 50 feet of the scaffolding was seen, the result gave 0·69424 as the value, while other observations dating back from 1751, made by Mayer, Delambre, Gauss, Struve, Bessel, &c., give a mean value of 0·1445 only, showing how essential it is to make exact allowance for refraction in determining the measurement of heights trigonometrically.

The Author next describes the re-survey of Berlin (begun in 1876), under the superintendence of Mr. v. Hoegh. The base "Marienthurm Rauenburgh," was 5 miles long, and on it was founded a system of seven triangles with their vertices on the Marienthurm. The twenty-one angles of these triangles were read

thirty times, and gave (with a circle $10\frac{1}{2}$ inches in diameter), a mean error of $3 \cdot 03''$. In the extension of the survey by minor triangulations of the 2nd, 3rd, and 4th order, the angles were respectively read, fifteen, ten, and five times.

In the very heart of the city, comprising about $7\frac{1}{2}$ square miles, there are about one hundred and sixty stations of the 1st, 2nd and 3rd order. Where these stations are not the tops of church steeples, lightning-conductors, &c., they are marked with a cross, on stone metal or wood, and are again determined by being many times connected by observation with neighbouring fixed points. On this triangulation is founded a polygonal network. The direct measurement of the sides of this polygon gave a mean error of 5·7 inches per mile over the computed measurement, and a complete series of experiments with rods (*Latten*) 5 metres, and steel chains 20 metres long, resulted in every case in favour of the former.

The sides of the polygons are marked with an incised cross, the junction of two sides by an anchor, and all the sides are laid on the pavement behind the lamp-posts for security and for ready reference. The survey of the details follows in fifteen sections, which again are sub-divided and worked out separately.

The mapping is done in duplicate, viz., a general map to the scale $\frac{1}{1000}$, and detail maps, scale $\frac{1}{250}$. All the sheets are engraved on copper plates, and struck off and published, so that every land-owner can easily prepare a correct map of his own estate.

With the survey, a series of levels is attached, consisting of twenty-four principal and seventy-two minor sections, and comprising 8,743 heights. The total cost has been 25,000*l.*

The Author also describes a survey he began of the city of Munich. As the basis of this survey, he takes a side determined from the Rhenish triangulation, and the system comprises 3,000 acres surrounding the city.

For the most part the stations could be fixed on flat roofs, and consisted of an iron plate screwed down and fitted with a cylindrical case or socket, in which high rods or poles could be secured by means of pins, and their verticality ensured by suitable mechanical appliances. Each socket or shoe, with support, weighed about 6 lbs., and cost 5*s.* 6*d.*

On the ground, the stations are marked by stones about 2 feet long, and 6 inches square in section, with a vertical semi-circular groove in the middle of one side, to admit of fixing the signal pole. Under each stone is another stone, on which the exact station point is marked by an incised cross.

In the interior of the city, however, the stations were marked on the pavement by cast-iron posts 2 feet long and 3 inches square at top, with pear-shaped head, in which is a hole for securing the signal-pole, and under this was a detached cast-iron reference-point. These stations were difficult to fix, and at the most only forty could be set up by five men in ten hours. Each weighed 44 lbs., and cost about 3*s.* 7*d.* Each station was connected by direct measure-

ment with at least two fixed objects, and the sides of the polygon, 34 miles in all, were again measured with 5-metre rods (*Latten*), by different parties, and in different directions.

In consequence of the favourable construction of the buildings with flat roofs on which to fix the stations, the triangles could be made almost equilateral.

W. H. E.

Reports of the United States Testing-Board.

(The American Engineer, vol. vi., July 13 to August 17, 1883.)

This Board was appointed by Act of Congress in 1875, to test iron, steel, and other metals, but owing to the withdrawal of the grant it was dissolved in 1879.

The results of its labours during that period are published in two volumes, the first of which was issued in 1879, and contained a "Preliminary Report on the alloys of Copper and Tin," by Prof. R. H. Thurston, and a "Report on Experiments on Wrought-iron Bars and on Chain Cables," by Commander L. A. Beardslee, U.S.N.

The second volume has been only recently issued, and comprises a number of reports on various subjects, most of which, owing to the sudden cessation of the work of the Board, are incomplete. They are as follows, viz.:—

"Report on a preliminary investigation of the properties of Copper-Zinc Alloys," by Prof. R. H. Thurston.

"Records of Tests of the Copper-Tin-Zinc Alloys," by the same Author.

"Report on the strength of Iron Girders and Columns," by William Sooy Smith.

"Results of Tests and Analyses of Steels," by Alexander L. Holley.

"Report on the Tests of quality of Steel for Tools," by David Smith; and an Appendix, viz., "Translation of a Memoir on the Planing of Metals," by Mr. Tresca.

Accompanying these reports, on their transmission to the President of the U.S. by the President of the Board, Colonel S. S. Laidley, are some general remarks by the latter with reference to the investigation, and the desirability of their being continued, especially as regards the testing of iron with the machine in their possession.

The first of these Reports, viz., on the copper-zinc alloys, is the subject of a detailed digest published in "The American Engineer."

For investigating the mechanical properties of the alloys of copper and zinc, the experimental bars were 28 inches long, and 1 inch in square section, in two series of castings, the first differing in composition by a regular difference of 5 per cent., commencing with an alloy of 5 per cent. of zinc, the next 10 per cent., and so

on up to pure zinc; and the second series commencing with 2½ per cent. of zinc, the next 7½ per cent., and so on up to 97½ per cent.; these were tested under tensile, torsional, and a few under compressive, strains. Tables are given in detail of the compositions of the bars, their deflection and moduli of rupture and elasticity, &c., under tensile strains, and diminution in sectional area at the moment of rupture. Particulars are also given of the colours and appearance of the skin and fractured surfaces. A Table of the results of torsional stress agrees in general with those for tensile strain. The compressive strain was exerted by a 100,000-lbs. testing-machine, the pieces experimented on being turned cylinders 2 inches long and 0·625 inch in diameter. A summarised Table comparing the whole of the results obtained by the experiments is given.

D. G.

On the Influence of the Inequality of the Material upon the Tensile Strength of Bars. By Dr. H. Zimmermann.

(Centralblatt der Bauverwaltung, 1883, p. 220.)

The question whether the fact that a long bar of iron has a smaller tensile-strength than the pieces obtained by its fracture, is to be explained, according to Bauschinger, by an increase of strength throughout the bar under tension, or only by the inequalities of the material, is philosophically discussed with reference to the experiments of Fairbairn, Vicat, Kirkaldy, Wöhler, Chaplin,[1] and Bauschinger. The Author points out the contradictory explanations given to the phenomenon by the various authorities, and comes to the conclusion that the unequal condition of the material must be looked upon as its chief cause, although an explanation cannot be given in what manner it is caused, inasmuch as it is impossible to prove the change of strength of one particular section independently of others.

M. A. E.

The Adoption of a Standard Brick in Switzerland.

(Report presented to the General Assembly of Cantonal Delegates at Berne. Dec. 9, 1882.)

By F. Fayod.

(Bulletin de la Société Vaudoise des Ingénieurs et des Architectes, June 1883, p. 13.)

The best method of developing the art of building in brick has occupied the attention of architects and engineers in Switzerland for some years, and with this view it has been determined to attempt to fix a certain standard size of brick, and a report was

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[1] "The American Engineer," vol. iv., No. 5.

presented to the Swiss Society of Architects and Engineers, in which the dimensions recommended were 9·84 inches by 4·72 inches by 2·36 inches. As, however, these dimensions were not agreed to by all sections of the society, a special federal commission was appointed in December 1882, to inquire into the subject.

The Author first of all gives a brief account of the bricks that were used by the Assyrians, Egyptians, and other ancient peoples. He then gives tables of the dimensions of the bricks used from remote periods up to the 17th century, and of those in use at the present day in Italy, France, England, Belgium, Austria, Germany, and Switzerland. From these tables he shows that the standard size should be between the limits of 9·45 inches long, 4·33 inches broad, and 1·97 or 2·56, or 2·76 inches thick, and 11·63 inches long, 5·12 inches wide, and 1·97 or 2·56 or 2·76 inches thick, or taking a mean, the size should be 9·84 inches by 4·72 inches by 2·36 inches. This size is made at the present time, as is also that of 9·84 inches by 4·72 inches by 2·76 inches. The Author is greatly in favour of the thicker brick, and a good deal of the Paper is taken up with a discussion of the possibility of properly burning it, many of the Swiss brick-burners having stated that they cannot burn bricks having a greater thickness than 2·36 inches. In reference to the thicker bricks, he remarks: 1st, that, the other dimensions remaining the same, the resistance increases with the thickness. 2nd. There is perhaps rather more difficulty in drying a thick brick, but care in mixing the beds of clay, the addition of sand, gradual drying, &c., will readily get over it. 3rd. In burning, the bricks must be carefully placed in the kilns, as the gas will follow the shortest route to the outlet; the bricks must be arranged so as to oppose obstacles to its escape in this direction, while facilitating its passage by the longer route. The bricks, after being dried in the sheds, should be further dried by hot air from the kilns before being burnt. All apertures by which air could pass into the kilns must be carefully closed, and the cooling of the bricks must be gradual. 4th. When colour is of importance, attention must be paid to the fuel. Coals of inferior quality frequently contain extraneous matter which is deleterious to good colour, and also to the weathering qualities of the bricks, and is sometimes the cause of efflorescence. 5th. With the same material there will be a better output of first-class bricks with a 2·76-inches than a 2·36-inches thickness, because vitrification does not begin so soon. Of course the best quality cannot be obtained from clays which are very chalky, earthy, or sandy, but with careful manipulation very fair bricks may be made from very moderately good earth.

The Author conducted some experiments at the Horn brickfields of Mr. Bourry, where the bricks are made by machinery and burnt in Hoffmann kilns. These experiments were performed with eight varieties of earth, three blue, three yellow, one sandy and one earthy. Bricks were made from each variety separately, and also from mixtures of different kinds; their dimensions were 9·45 inches

by 4·53 inches by 2·76 inches. They were dried under different conditions, according to their kind, and burnt carefully in kilns with other bricks. The result was that each different clay and each mixture produced bricks of different colours, but all well-burnt and sound.

With regard to the question of price, of course if the manufacturer sells his bricks by the thousand, without reference to size, the smaller they are the better for him. The contractor, too, is apt to prefer small bricks, because with them he uses more mortar, which costs him less; but, on the other hand, he requires more bricks per cubic yard (the number of bricks of different sizes in a cube metre of work are given), and there is more labour in setting them, so that what he gains in one way he loses in another.

In regard to the quantity of mortar, Dr. Boehme's experiments at Berlin, in 1875, proved that no more mortar than was actually necessary to keep the courses horizontal and effect the cohesion of the bricks (for which purpose joints 0·4 inch thick are ample) should be used, as, whether the mortar becomes more or less hard than the bricks, the result is in either case to reduce the strength of the work. Experiments made with blocks of twenty sound bricks, one set of blocks cemented with various kinds of mortar and cement (the joints 0·4 inch thick), another set consisting of bricks laid dry, and surrounded with cement simply to keep them together, gave, as mean resistances to compression: for the first set, 1,618 lbs. per square inch to cause splitting, 1,934 lbs. per square inch for the destruction of the bricks; and for the second set, 2,202 lbs. per square inch to cause splitting, and 2,291 lbs. per square inch for destruction, showing that the dry bricks gave a mean resistance of one-third more than those set with mortar before splitting, and one-fifth more before destruction. The Author therefore concludes that to secure the greatest strength thick bricks with a minimum of mortar should be used.

The Author suggests that the price of bricks per thousand should vary according to the number required per cubic metre of work, so that the manufacturer may be paid according to the size of the bricks. Finally, he recommends that the standard brick should have the dimensions 9·84 inches by 4·72 inches by 2·56 inches.

W. H. T.

On the Relative Cost of Retaining-Walls built in Brick and in Columnar Basalt. By P. H. Kemper.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1883, p. 75.)

Mr. Kemper collected data from different public works, executed in brick and in basalt, of late years, and compared their actual cost prices. Basalt being the heavier material, a saving can be effected in the thickness of walls by employing this material. On the other hand, the adhesive strength of mortar on basalt is only about

half of that on brick; but the superior weight restores in friction on the joints what may be lost in adhesion.

The Author instances works executed, amongst others, the basalt wall of the lock at Flushing, where 27 per cent. was saved, and the quay-wall at Maasluis, where 11 per cent. was saved by building in basalt instead of in brick. For these works the actual cost of 1 cubic metre of basalt masonry was 16·40 florins; 1 metre cube of klinker brickwork, 18·88 florins; of stock-bricks, 17·67 florins. At the lock at Vreeswijek the price paid for basalt masonry was 15·90 florins, for brickwork 16·07 florins per cubic metre. The mortar used for basalt is sand concrete, at 12 florins per cubic metre; for brickwork, mortar of equal parts of shell-lime and Rhenish trass.

In walls up to 4 metres high the saving is not appreciable, but it rapidly increases with the height.

According to experience, columnar basalt is preferable to brick:—in walls exposed to damp, such as retaining-walls for quays and locks, where the water-line is oscillating and the backing wet, also because basalt is of greater specific gravity; it is not liable to crumble away in frosty weather; its cost of maintenance is considerably less; and, in cases of settling and subsequent repairs, the material is not lost by the breaking out, but can be used again, which is not the case with brickwork. For large works and walls of great height basalt gives a better appearance than brick.

To the Paper are added diagrams and Tables, showing the dimensions and stability of retaining-walls built of the materials referred to.

H. S.

The Inspection of Cement. By W. J. Condon.

(The American Engineer, vol. vi., 1883, p. 46.)

The Author, who is connected with the Boston (Mass.) sewerage works, and has had considerable experience in the testing of cements, mentions that the matter has been under the consideration of the American Society of Civil Engineers for some time past, but that their report has not yet been published.

In his opinion, the results obtained by testing cement in a pure state, viz., unmixed with sand, are of but little value, the comparative tensile strengths of the same series of cements being often reversed when mixed with sand; also the belief that the quality improves in proportion to the increase in specific gravity has proved to be fallacious.

The finer a cement is ground, the less will be its weight; and its tensile strength, if mixed pure, will be much less than that of the coarser ground; whereas, when mixed with sand, the finer ground cement will resist the greater strain.

A comparison is made between Portland cements imported into America from Germany and England, the former of which is the

finer ground. Three examples of German cement are mentioned, in which the residuum from a given quantity sifted in a sieve of 14,400 meshes per square inch was 7, 22, and 26 per cent.

Diagrams are given comparing the tensile strength per square inch of mortars made in the proportion of 1 of cement to 2 of sand of an English Portland cement, of which about 38 per cent. was retained in a 14,400-mesh sieve, and of a German Portland cement, of which about 23 per cent. was retained in the same description of sieve (obtained from an average of five briquettes in each instance). There are also diagrams of the results given by a cement in its original condition as received from the manufacturer, comparing this with the siftings of the same cement which have passed through sieves of 6,400 and 14,400 meshes per square inch respectively, each grade being mixed with sand in the proportion of 1 to 2, 1 to 3, and 1 to 5, and tested after intervals of a week, month, six months, and year, which demonstrated the beneficial effect of fine grinding.

But little reliance can be placed upon colour as a test of quality.

The present method of testing in the Boston works is described, the form of the briquette being of the figure 8 pattern, and the breaking area 2¼ square metres.

The Author recommends that a standard method of testing should be agreed on and generally adopted, and suggests that the German method should be taken as a basis, in which the test briquettes are made by mixing cement with sand in the proportion of 1 to 3, and broken after an immersion in water of four weeks.

D. G.

On the Influence of Sand on the Strength of Cement-mortars.

By H. Arnold, of Wilhelmshaven.

(Zeitschrift des Architekten-und Ingenieur-Vereins zu Hannover, vol. xxix., 1883, p. 495.)

After observing that not only the quality of the cement used, but that of the sand also, is a very important factor in the composition of mortar, the Author remarks that in the case of sand, beyond general vague directions that it must be "clean and sharp," no detailed classification of the characteristics of different kinds, with directions how to obtain in all cases a normal or standard sand of uniform quality, was generally available for practical purposes until the publication of the valuable results of experiments carried out at Wilhelmshaven since 1877, in building the second entrance to the harbour. Taking first the ordinary local (Dangast) sand, a standard or normal sand was obtained from it by washing and sifting in the prescribed manner. This mixed with cement in the regulated proportion of 1 cement to 3 sand, gave a mortar whose tensile strength after seven days setting was 5·93 kilograms per square centimetre (84 lbs. per

square inch), and after twenty-eight days 6·60 kilograms, which does not nearly approach the standard of 10 kilograms prescribed in all contracts. An experiment similarly conducted with Berlin normal sand gave as follows:—

After 7 days	10·56 kilograms.
„ 28 „	15·10 „

being an increase of 43 per cent. in the interval, and 78 and 129 per cent. respectively higher than when Dangast sand was used. Specimens of Dangast sand and cement sent to the Royal testing factory at Berlin gave the following results:—

	After Seven Days.
Dangast sand	11·28 kilograms.
Berlin „	16·80 „
Difference . .	=49 per cent.

while experiments at Wilhelmshaven with Berlin sand and the very same cement gave—

	After Seven Days.	After Twenty-eight Days.
	Kilograms.	Kilograms.
with Dangast sand	9·06	9·74
„ Berlin „	14·24	18·44
Difference . . .	= 57 per cent.	89 per cent.

The increase in strength from seven to twenty-eight days is therefore 32 per cent. for Berlin sand, and 7½ per cent. for Dangast sand, and from these and other experiments it is abundantly proved that "the quality of the sand not only exerts considerable influence on the first setting of the mortar, but also materially influences the progressive hardening of it."

Further trials with the same cement, but with the various kinds of sand specified below, were made in order to test the influence of the sand itself.

1. Dangast ordinary building sand, weight 1·61 kilogram per litre (100 lbs. per cubic foot); size of grain, very unequal and somewhat dusty; not very sharp.

2. Dangast sand No. 2. The same sand after further sifting; a somewhat smoother grain.

3. Dangast normal sand, prepared from No. 1 by washing and sifting. Weight, 1·506 kilogram per litre; grain, reddish and of uniform size; not very sharp. The microscope showed a rounding of the corners of the grains of quartz.

4. Wilhelmshaven common blue sand. Very sharp and extremely fine grain; contains hardly any soluble particles of mud and silt, and weighs 1·267 kilogram per litre.

5. Wangeroog sand. A somewhat coarser, but still a fine, very sharp clean sand, free from dust; weight, 1·47 kilogram per litre.

6. Berlin normal sand. A sharp, clean, whitish quartz sand of uniform grain, and weighs 1·547 kilogram per litre.

Mortars made with these kinds of sand, and the same cement, in the regulated proportion of 1 of cement and 3 of sand, gave the following tensile strength :—

	After Seven Days.	After Twenty-eight Days.
	Kilograms.	Kilograms.
Wilhelmshaven blue sand . . .	7·15	9·40
Dangast normal „	8·78	11·10
„ No. 2 „	8·98	11·04
„ common building sand . .	11·60	13·00
Wangeroog sand	13·58	16·74
Berlin normal „	17·60	21·94

These results show that the strength of mortars similarly made with the same cement, but different kinds of sand, depends on the coarseness and size of the grains of sand; and that in sands of equal size of grain that is the best whose grain is the coarsest. (Compare Berlin and Dangast normal sand in the above Table, where the difference in the strength of the mortar is about 100 per cent.) In order to determine the influence of the size of the grain, comparisons were made with seven specimens of Dangast sand of various sized grains, and also with granite chips, the result always being in favour of the granite chips. This also came out of the experiments, viz., that in sands of equal coarseness of grain that is the best whose grain is largest. (Compare also in the above Table Berlin normal sand with Wangeroog sand, where the difference is about 30 per cent.) It was further established that coarseness of grain is a more important factor in the quality of a sand than the size of grain; and also that "a coarse sand free from dust gave better results than a fine sand of equal sharpness of grain." And further it was shown that sand containing uniformly sized grains is not always the best, since the ordinary Dangast building sand, which is somewhat dusty, invariably gave more satisfactory results than the sifted and washed Dangast normal sand of uniform size of grain. The Author concludes by saying that, although different kinds of sand give materially different results in similarly prepared mixtures of mortar, it will not be justifiable in ordinary masonry to alter the prescribed proportion of cement and sand, viz., 1 to 3, unless the exact quality of the sand employed is known; and he recommends—

1. That the normal sand of the Imperial Testing Station at Berlin should be declared officially to be the only prescribed normal sand as regards not only size, but also sharpness of grain, and that thereby a standard for the strength of cement and sand mortars should be established.

2. That in all notices regarding cement, a comparison of results with this normal sand and with local building sands should be set forth.

3. That both the seven days and the twenty-eight days tests should be published, in order to obtain a scale of increase of strength in cement and sand mortars.

W. H. E.

Concrete as a Building-Material in Combination with Iron.

By W. E. Ward.

(The American Engineer, vol. vi., 1883, p. 12.)

After remarking on the unreliability, in case of fire, of unprotected iron associated with combustible materials for building purposes, the Author recommends the adoption of walling and flooring composed of wrought iron imbedded in concrete.

A house erected near Port Chester, N.Y., is instanced as a successful example of this system. The concrete for the heavy wall-work was in the proportion of 1 of cement to 4 of sand and fine gravel, using a minimum quantity of water for mixing. In place of gravel, small-sized stone chippings would be preferable, and were used for the flooring and roof concrete, which for these latter purposes was in the proportion of 1 to 2.

An experimental test was made on a 4-inch **I** section wrought-iron rolled joist, 12 feet long, weighing 30 lbs. per yard, imbedded in a mould filled with concrete 12 inches deep and 5 inches wide, with projecting ledges on each side of the under-side of the beam, the bottom of the wrought-iron joist being 1 inch above the under-side of the mould, there being consequently a depth of 7 inches of concrete above the top of the joist. By placing the wrought-iron joist in this position, the tensile strains are met by the iron, and the compression by the concrete.

After thirty days it was tested by being placed on supports, with a 3-inch bearing at each end, and subjected to a load of 9,500 lbs., applied as a knife-edge at the centre. The deflection was $\frac{7}{16}$ inch, without sign of rupture or permanent deflection on removal. (For future constructions it is proposed that the wrought-iron joist should be of $\perp$ section, to avoid waste of metal.) The flooring between the beams was formed of concrete, in which were imbedded, near the under-surface, wrought-iron rods $\frac{5}{16}$ inch in diameter, the total thickness of floor-slab being $3\frac{1}{2}$ inches; this was laid upon temporary planking, channel-ways being moulded in the outer walls for receiving the ends of the slabs. Paper was laid between all bearings of joists and floorings on walls, to prevent adhesion and so permit of movement under varying temperature and load.

The only test made on the combined strength of floors and beams together was in a case where the span was 18 feet, and the distance between the beams, from centre to centre, was 6 feet; the distributed load per beam was 30 tons; the section of beam 7 inches by 16 inches, with an inclosed wrought-iron **I** joist, 7 inches deep, and weighing 55 lbs. per yard. The permanent deflection was nil. Experiments upon the rigidity of partition walls 8 feet high and $2\frac{1}{2}$ inches thick, formed of $\frac{1}{4}$-inch iron rods imbedded in concrete, gave results equal to the strength of a brick wall of the same height 8 inches thick.

The Author is of opinion that for most dwellings, outer walls

composed of two thin concrete walls, with a space between them of from 6 to 10 inches, could be built to a height of from 30 to 40 feet, at a cost not exceeding that of first-class brickwork, at the same time serving as a means of warming by the passage of hot air through the space, the floors also being easily constructed double for the same object, as carried out in the building instanced.

Particulars are given of the fuel necessary for maintaining a certain temperature over a given area of walling under particular conditions, and in conclusion it is urged that such a system of iron joists combined with concrete, can sustain much greater loads than the iron could alone do, and at less cost than any other system of flooring now in use; also that it affords a better means of warming buildings than by steam or hot water, at the same time ensuring perfect ventilation and security against fire.

D. G.

Plaster Walling as used in Arakan.

By Capt. R O. Lloyd, R.E.

(Professional Papers on Indian Engineering, Roorkee, 1883, p. 101.)

In both Sandoway and Kyoukpyoo, where there is an annual rainfall of over 200 inches, the walls of many of the government buildings and private houses are made of plaster instead of planking, as is generally the case in Burmah. This plaster-walling seems to have great advantages over planking. It is cheaper, cooler, prevents sound passing from one room to another, and is easily and cheaply kept clean by white or colour washings; it may also be painted, if preferred. Although the plaster walls are double, they do not appear to harbour vermin, insects, &c., as might be expected; and if the work is done as described, the wooden framing separates the wall into squares of about 3 feet, and it is impossible for rats to work from one square to another. It is necessary to provide some ventilation for the rooms, either by wooden lattice-work at the top of the wall, or by any other method. The plaster walls, if properly made, last well, even when exposed to the weather. The Circuit-house walls at Sandoway are said to have been built ten years, and they are in perfect order, although they have not been renewed. In Sandoway the work costs about 12 rupees per 100 square feet, not including the price of the wooden framing; but of course will vary according to the price of materials.

For one bay of walling 10 feet square, framing 4 inches by 3 inches is put up in the ordinary way between the posts. Small green bamboos $1\frac{1}{2}$ inch or 2 inches in diameter are then cut into such lengths that they may fit tightly when placed horizontally between the vertical pieces of framing. Where sawn wood can be got cheaply, it would be better to substitute for these bamboos battens which could be nailed to the frames. There is a little

trouble experienced in getting the bamboos fitted in nicely; if they are slightly too long they are apt to split in being put in, and if too short it is of course difficult to fix them except by wedging. Bamboos, however, are used at Sandoway, and do very well. Dry ones are unsuitable, as they would split. Dry bamboos, of as large diameter as can be obtained, are then cut into lengths so as to fit vertically between the framing, split open and beaten out flat. These form the groundwork on which the plaster is laid; they are placed vertically on either side of the horizontal bamboos, with the inside of the bamboo outwards, and kept in position by narrow strips of bamboo; the latter are placed outside the split bamboos on each side, and are tied together with cane. There is now a double wall of split bamboo, which should be quite firm and rigid. The inside of the bamboo is turned outwards, as that forms the best surface for the plaster to be laid on. The projecting pieces of the bamboo joints should not be dressed off. Long pieces of string are now hung closely together on the bamboo strips, and should reach down from one strip nearly to the next below. Old gunny bags cut up and pulled to pieces form very good material for this purpose. The surface is now ready for plastering. The workman in laying the plaster lifts up the string with his left hand and spreads the plaster on to the split bamboo; he then presses the string into it, and so ties the plaster down. Two coats of plaster are laid, the first having a very rough surface to receive the second. The plaster is mixed as usual for good plastering work, laid on as dry as possible, and well worked by hand; it is then kept damp for three days by being sprinkled with water before the second coat is put on. Owing to there being no sand obtainable within some miles of Sandoway, the plaster for a house lately built was made of only surkhi and lime; this, though the work was carefully done, is cracking slightly, but the plaster is very hard and good. *

On the Changes in the Beach of the North Sea Coast, in the Provinces of North and South Holland.

By P. C. van Kerckhoff.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1883, p. 90.)

For noting the increase or diminution of the sand beach, and of the seaward slope of the downs, heavy oak posts were driven parallel to the low-water line, and at distances apart of 1 kilometer. These mark out a permanent base line from Helder to the Hoek van Holland.

The low-water and high-water line at ordinary springs, and the line of the foot of the downs, are yearly measured with regard to their position to the base line. This was first done in 1843, and has been continued since. These observations show that between the post No. 0 at Helder and No. 20 the coast has been slightly scoured away. No change is perceptible since 1843 between Nos.

27 to 101. South of 101 there was a strong wash, particularly since 1861, at No. 104, amounting to 76 metres. As a general rule, the low-water line along the whole coast has crept landward, the beach standing steeper. The influence of the piers at Ymuiden harbour on the coast line seems to be only local. No theory can as yet be grounded on these observations, nor has any periodicity been discerned in the changes.

The Paper is accompanied by Tables and two diagrams.

H. S.

The Port of Marseilles in 1883. By D. Stapfer.

(Le Génie Civil, vol. iii., 1883, pp. 441 and 497, 1 pl.)

The old basin, a natural harbour at the southern extremity of the port, formed the whole of the port up to 1844. It has been gradually improved by the construction of the Customs canal in the last century, by the formation of a careening basin in 1829, and by the erection and enlargement of the quays at various periods up to 1855. A new series of docks were commenced along the coast towards the north in 1844; and the south outer harbour, the Joliette basin, the Lazaret and Arenc basins, the maritime station basin, the National basin, and the north outer harbour, have been successively constructed, being sheltered from the sea by a breakwater, which at the present time has a length of 11,790 feet. The breakwater consists of two straight portions joining at an angle; the southern portion, 3,561 feet long, pointing S.S.W.-N.N.E., and the northern portion, 8,229 feet long, pointing S.E.-N.W. Full descriptions are given of the various basins, of which the following Table furnishes a summary as regards area, depth, and length of quays:—

Name of Basin.	Area.	Depth of Water.	Length of Quays. Total.	Length of Quays. Used for Working.
	Acres.	Feet.	Feet.	Feet.
Old basin	65·1	9½ to 23	6,212	5,846
Annexes to old basin: Customs canal	1·6	13	3,443	2,820
Annexes to old basin: Careening basin	3·8	16½	1,811	..
Joliette basin	50·1	19½ to 44½	6,300	5,297
Annexes to Joliette basin: Connecting canal	2·0	19½	2,756	..
Annexes to Joliette basin: Side basin	4·3	10 to 19½	1,849	1,849
Lazaret and Arenc basins	51·4	23 „ 49	8,173	8,002
Maritime station basin	44·4	19½ „ 49	7,076	6,420
National basin	102·2	19½ „ 65½	13,188	12,334
Graving docks basin	12·5	26½	2,480	..
Pharo basin	2·5	0 „ 13	230	..
South outer harbour	5·6	6½ „ 36	1,249	..
North „ „	85·6	16½ „ 65½	..	..
Totals	431·1	..	54,767	42,568

The old basin was formerly reserved exclusively for sailing vessels, but as the number of these is regularly decreasing, some steamers are now allowed to use it. The Joliette basin, being the best situated for the town, is crowded with vessels; and though it has only a railway along one side, and no cranes or hydraulic machinery, the traffic at its quays is larger than that of any other in proportion to the length of quays. The Lazaret and Arenc basins are in the hands of a private dock company, which has amply provided these basins with hydraulic cranes and machines, greatly facilitating the unloading of cargoes; so that, though the traffic is almost exclusively import, it amounted to 570 tons per lineal yard of quay in 1882, whilst the traffic at the Joliette basin was 700 tons in the same period. The Chamber of Commerce has possession of the maritime station basin, but it simply lets the hydraulic machines and the sheds by the hour and day. The National basin has a straight length of quay along the breakwater of 2,950 feet, which is much used; and three moles have been recently constructed jutting out from the shore quay, increasing the available quay space, which is to be furnished with lines of way, sheds, and hydraulic machinery. A new railway station is proposed to be formed behind this and the maritime basin. Four graving docks open into a special basin connected with the National basin; the largest can hold a vessel 430 feet long, and is to be enlarged so as to be able to receive vessels 490 feet in length. The north outer harbour could be readily converted into a sheltered basin, as the breakwater extends 2,300 feet in front of it. The Rhone canal is to have its outlet in a bay on the northern side of this outer harbour. The Joliette, Lazaret, and Arenc basins have reached the limit of their possible traffic; but if the old harbour and the new basins were equally provided with railways, hydraulic cranes, and sheds, they would suffice for the increasing commerce of the port for the next ten years.

L. V. H.

The Working Arrangements at the New Quays at Antwerp.

By Van Bogaert.

(Bulletin de l'Association des Ingénieurs sortis des Écoles Spéciales de Gand, June 1883, p. 237.)

From some statistics given by the Author, it appears that the trade of Antwerp is steadily increasing; but whilst the average tonnage of the vessels is rising, the number of sailing vessels has greatly decreased, and the number of steamers is stationary, and the number of vessels leaving in ballast is diminishing. In 1881 the imports by railway were 1,303,000 tons, and the exports 1,124,000 tons, whilst 2,876,000 tons of exports and imports were conveyed by water, as compared with 639,000 tons in 1861.

Under existing arrangements at Antwerp, if an export cargo is

not available, the steamers find it advantageous to leave the port in ballast, and to be loaded with coal at Newcastle or Cardiff. At these ports, 200 tons of coal can be put in a vessel in an hour, at a cost of 2½*d.* per ton, whilst at Antwerp, in 1876, the same work could only be accomplished in a day, at a cost of 1*s.* 2½*d.* per ton. The steam cranes in the Campine Dock enable 40 tons to be deposited by two cranes in an hour, at a cost of 8¾*d.* per ton. The vessels, however, waste a good deal of time in getting into the docks, so that these cranes are little used for loading coal. The working arrangements of the new quays are destined to supply the want of means of rapidly loading and discharging vessels. The quay space along the new quays has a width of about 1,000 feet, of which 200 feet are covered by sheds; and five lines of way, running parallel to the quay, intervene between the sheds and a carriage-way 66 feet wide. One line of way is laid 10 feet from the face of the wall, for direct loading or unloading between the vessels and the trucks. A special line of rails, having a gauge of 13 feet, is set apart for the hydraulic cranes to travel along. The quay line of rails is connected by a series of turn-tables, placed about 230 feet apart, with three other parallel lines 200 feet away from the coping line. Two other main lines, parallel to the others, run along the whole length of the quay, and are connected with the quay lines. The turn-tables will eventually be worked by hydraulic power. Twenty-two hydraulic cranes are placed on the first section of the quay. Each crane stands on a carriage running on four wheels, and raised up so as to leave space for trucks to pass freely underneath. The jib of the crane extends 46 feet above the quay level, and 31 feet beyond the coping-line. The crane has two powers, one of 14 cwt., and the other 1½ ton, and is worked by water under a pressure of 50 atmospheres. Each crane can perform forty operations in an hour, so that four cranes could load 200 tons per hour, at a cost of about 0·4*d.* per ton; and in all probability a ton of coals will be delivered into a vessel at the same price as at the English ports, so that vessels devoid of cargo will no longer be obliged to go out in ballast. L. V. H.

Type of Lock adopted on the Scheldt and Meuse Canal.

By Baron QUINETTE DE ROCHEMONT, M. Inst. C.E.

(Annales des Ponts et Chaussées, 6th series, vol. vi., 1883, p. 5, 1 pl.)

The object of the new type of lock adopted on the Scheldt-Meuse canal is to reduce the time occupied by boats in passing through a lock, which at present, under the most favourable conditions, is at least from sixteen to twenty minutes on the French canals, though only five minutes on the Weaver and Erie canals. It is only by facilitating the transit that the network of waterways, now

being completed in France, can really compete with railways, and aid in developing trade. The ordinary locks have a cross-section so little exceeding the size of the boats, that these act like a piston in the lock, and their passage is thereby hindered. The method also of filling and emptying is unsatisfactory, and the sluice-gates too small. The new type of lock has its chamber 17 feet wide, and 126½ feet long, according to the recent standard requirements; but the depth of water is made 9¾ feet on the upper sill, and 8 feet 2½ inches on the lower sill. The lift is 13 feet 1½ inch; the gates are single; the filling and emptying is accomplished through culverts in the side walls closed by cylindrical sluice-gates of large diameter, and the lock and sluice-gates are worked by hydraulic machinery. The lock is placed on the towing-path bank, and the canal is made to its full width up to the lock, which dispenses with the delay occasioned by boats having to wait some 80 or 90 yards away from the lock till the preceding boat has left it, and the boat can wait close to the lock out of the way of the currents produced in locking. This arrangement, moreover, renders the erection of a second lock very simple in the event of the traffic requiring it. By increasing the lift from the ordinary limit of between 6 feet 7 inches and 8 feet 10 inches up to 13 feet 1½ inch, the number of locks, and consequently the impediments to traffic, are considerably reduced, whilst the cost of construction, by adopting the lift of 13 feet 1½ inch in place of a lift of 8 feet 2½ inches, is diminished 11 per cent. The failure of side passages, for the escape of the water, to remedy the obstacle to the entrance and exit of a boat having a cross-section approximating to that of the lock, rendered it necessary to enlarge the cross-section of the lock itself either by widening or deepening it. If an increase of width had been adopted, wider barges might have been built by the traders, thus both annulling the advantage sought to be gained and rendering the crossing of these wider barges in the canal difficult. Accordingly the depth has been increased by 1⅓ foot over the lower sill, which also has the advantage of causing less expenditure of water in locking than an increased width. The culverts for filling and emptying the lock are built all along in the side walls, having their openings at each end beyond the gates. They communicate with the lock-chamber by four side openings along each face of the side walls. The culverts are 5¾ feet in diameter, and the side openings 2 feet 7½ inches wide by 2 feet 3½ inches high. An iron pipe, 5 feet 5 inches in diameter (having its upper end above the water-level of the upper pool, and its lower end resting upon an india-rubber ring encircling a circular aperture, 5 feet 1 inch in diameter, which communicates with the lower pool), moves vertically in a well into which the culvert opens, and thus serves as a sluice-gate for regulating the flow of water through the culvert. By raising or lowering one of these pipes at either extremity of the culvert in each of the side walls, communication between the pools and the lock-chamber is readily established or closed; and

the size of the apertures causes the operation of filling or emptying to be rapidly accomplished, whilst the side openings being low down, far apart, and small, admit or draw off the water from the chamber below the boat without producing currents liable to affect it. The lock gates formed with a single leaf have the advantage over double gates of being easily worked by only one man, of being exposed to smaller and less complex strains, of being more watertight, easier to construct, and requiring less material, as well as being more easily taken out and repaired. A single gate necessitates, indeed, a 20-feet longer lock-chamber, but this increase in the first cost, estimated at £40, is compensated for by the saving realised at each renewal of the gates, amounting to £92. The gates are constructed of galvanized iron, and without sluices, as all the sluicing is performed through the culverts. In the new type of lock, and by the aid of hydraulic machinery for working the gates and sluices, the passage of a boat should not occupy more than nine-and-a-half minutes, thus reducing by one half the time of locking. Moreover, the saving in time by boats waiting for their turn to enter the lock would be at least as much, so that the total saving in time at each lock might be reckoned at twenty minutes. The additional cost of the lock, compared with one having the same lift of the ordinary type, is £412, and the expense of the hydraulic machinery is £588, making a total addition of £1,000. The interest on the cost of the hydraulic machinery, including its gradual repayment, would be less than the salaries of the assistant lock-keepers, who could be dispensed with. Irrespective of this, the gain from the saving in time alone, for the average number of boats passing along the canal, would be equivalent to nearly 6 per cent. on the total additional expenditure. Moreover, the capacity of the canal for traffic would be doubled, and the service would be more regular and rapid.

L. V. H.

Construction of a Dry-Dock in Quicksand. By — ZIMMERMANN.

(Zeitschrift des Architekten- und Ingenieur-Vereins zu Hannover, vol. xxix., 1883, p. 293.)

This dock was built at Hamburg for the Hamburg-American Steam Packet Company. The only available site was a narrow strip on the bank of the Elbe, perpendicular to the river, partly below high water, and the soil so loose and porous that it would only stand at a slope of 1 in 4. The excavation was 390 feet long, 66 feet broad, and about 23 feet below low-water level as a maximum.

Want of space precluded the formation of a cofferdam, of several rows of sheet piles of varying heights, which would have been the safest arrangement, so it had to be constructed of a single line of sheet-piling, which not only had to support the entire pressure

of the surrounding soil, but, owing to its unavoidable imperfect watertightness, allowed the water to percolate through the sides. The first step, therefore, was the setting up of four turbines for pumping out the water. The work demanded of them was the lifting of 15,275 cubic yards, a maximum height of 23 feet in three-and-a-half hours; but they did it perfectly in half that time—that is, they lifted on an average 2·42 cubic yards per second.

In order to limit the depth to which the piles had to be driven as much as possible, the bottom of the dock was not made horizontal, but rounded, to correspond with the form of a vessel, so that to drive the piles down to 23 feet below low-water level was sufficient. The space enclosed by the piling was then dredged out. The concrete employed for the foundation was formed of 9 parts Lüneburg lime, 7 trass, and 16 sand, mixed with twice that volume of broken stone, and was at first shot out for the entire thickness of the floor of the dock at once, by means of a wooden shoot or funnel attached to a travelling crane; but this arrangement did not answer well, for the shoot often splintered and broke, so an iron one had to be substituted. After the concrete had lain three months under water, the water was pumped out, and the concrete, though not perfectly set, was found sufficiently watertight. Splinters of the wooden shoot were found in the concrete floor, and their removal caused strong springs or leaks, but these were successfully stopped by iron-cement.

On the concrete floor the side and front walls were built of brickwork, and carried up to summer flood-level, with a rebate or recess for a caisson, and all round the dock is a quay-wall reaching above highest flood-level.

After a time it was observed that the butting of the caisson against the walls loosened the mortar, and the recess was not watertight, but it was made so completely by a facing of planed cast iron with concrete backing.

The weight of the empty dock alone is not sufficient to resist the upward thrust of the water at very high tides; but when loaded with the weight of a ship there is, of course, an abundant margin; and when no ship is in dock it is arranged that so much water shall be admitted as will satisfy the conditions of safety. The work was carried out in 1868 to 1870, and cost £65,000.

W. H. E.

The American System of Dry-Docks.[1] By J. J. Little.

The Author was requested to examine and report on the system of timber dry docks, erected by Messrs. Simpson at Boston, Brooklyn, Philadelphia, and Baltimore, and the granite docks in

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[1] This pamphlet is in the Library of the Inst. C.E.

the government yards at Charleston and Brooklyn, with the object of ascertaining the best material to be employed in a new dry-dock at St. John's, Newfoundland.

Four granite docks have been built in the United States, and one is in course of construction at San Francisco, whilst ten of the Simpson timber docks have been constructed. The granite docks have occupied at least seven years in construction, whereas the largest Simpson dock has been built in less than eighteen months. The government officials at Washington give the preference to timber docks, and it is contemplated that the necessary enlargement of the existing government granite docks will be executed in timber. The three small timber docks at Boston, built nearly thirty years ago, and in constant use, show hardly any signs of decay, and could be easily made perfectly sound at a small cost. There are two timber docks at Brooklyn,[1] 510 feet and 610 feet in length, capable of docking the largest ocean-going steamers, and they can be pumped dry in one and a half and two hours respectively. These docks are easily kept in perfect order, and showed no signs of leakage. The timber docks at Baltimore and Philadelphia, 504 feet and 450 feet long respectively, completed some years ago, have cost hardly anything in repairs, are in perfect order, and have proved very satisfactory in working. The granite docks, on the contrary, besides being much more costly to construct, require a far greater expenditure in repairs, are liable to be injured by frost, and become leaky. Various particulars of the different docks are given in reports and letters appended to the report. The Author concludes by strongly advocating the adoption of timber docks in preference to stone docks, in countries exposed to frosts, not only on account of their great durability below the water-line, but also owing to their more rapid construction, less cost, cheaper repairs, easier working, and being more healthy and lighter for the workman.

L. V. H.

Description of the Earthwork on the Upper San Joaquin Canal, California. By G. J. SPECHT.

(Wochenschrift des österreichischen Ingenieur-und Architecten Vereins, 1883, p. 221.)

This canal has for its object the irrigation of about 100,000 acres of land in the southern part of California, where the annual rainfall is not more than 8 inches, the soil when irrigated exceedingly fertile, and the climate favourable for growing fruit. It is led off from the San Joaquin River (which rises in the western slopes of the Sierra Nevada, and has a minimum discharge of about 1,350 cubic feet per second) by the construction of a weir with crest

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[1] Minutes of Proceedings Inst. C.E., vol. lxxiii., p. 423.

level with the bed of the canal, and is designed to carry about 350 cubic feet of water per second. The weir is built of rubble-stone with fascine packing, and rests on a granite bed, and is provided with a wooden under-sluice.

The cross-sections of the canal are :—

—	Bottom-Breadth.	Depth of Water.	Slopes.
	Feet.	Feet.	
From station 0 to station 207	75	4½	1½ to 1.
„ „ 207 „ 311	44	4½	1½ to 1 for a height of 6 feet, then 1 to 1.
„ „ 311 „ 1,050	24	4½	2 to 1 for a height of 6 feet, and then average 1½ to 1.

The computed velocities and the discharge per second in these sections are respectively :—

v_1 = 1 foot. Q_1 = 406 cubic feet.
v_2 = 1½ „ Q_2 = 393 „
v_3 = 2¼ feet. Q_3 = 354 „

The canal is for the most part made in sidelong ground, partly in cutting and partly in embankment, and the soil is so close and watertight that in some sections it has been taken entirely through "made earth." After the ground had been sufficiently loosened by a plough, the removal and deposit of the material was effected by so-called "dump-scrapers" and "buck-scrapers," the former drawn by a pair of horses, and ordinarily containing about 0·08 cubic metre or 3 cubic feet, the latter drawn by four horses, and holding, according to the tenacity of the soil, from 13½ to 70 cubic feet. The bottom or body of the dump-scraper is formed of ¼-inch steel plate, 30 inches wide and 20 inches long, with a curved front edge or cutter; the back is of ⅛-inch iron plate, 26 inches wide, 13 inches high, and riveted to the body; the sides are formed of wood 1½ inch thick, curved at the top, and covered with ¼-inch iron plate, and tapered off at one end to form a handle. On each side or cheek, a ring and chains are fixed for attaching the horses.

The "buck-scraper" consists of a back-board, formed of two planks, 9 feet long, 20 inches wide, and 2 inches thick, to the bottom of which is attached a projecting plate of steel 7 inches wide and 2 inches thick. The cheeks are of wood 2¾ inches thick, 4 inches broad, and 20 inches high, curved and plated with ⅜-inch iron. At the back a tail-board is attached at a certain angle, and furnished with an adjustment for adapting the scraper to the slope of the ground, and on the back-board are fixed rings and chains for haulage.

The manipulation of both scrapers is somewhat similar. The machine is taken to the site of the canal excavation, where the soil has already been loosened by the plough, is then dragged

forward by the horses filling as it goes, and, having arrived at the proper place, is tipped over; then, running on the iron-plated cheeks, it is taken back, re-filled and again moved forward, and so forth; and this loading and tipping goes on almost without stopping. Ordinarily from four to six scrapers were worked together; one behind the other, and the length of lead never exceeded 100 feet, and with the buck-scraper was usually about 60 feet.

In good soil, with a lead of 100 feet, a dump-scraper would remove 35 cubic yards of earth in a working day of nine hours, at a direct cost of about 4*d.* per cubic yard; and a buck-scraper, with a mean lead of 66 feet, 113 cubic yards in nine hours, at a cost of 2*d.* per cubic yard, exclusive of cost of superintendence, &c. For working in the hill-side two kinds of ploughs are described—one called the "side-hill plough," with a double-edged reversible coulter, so as to work backwards or forwards; and another, V-shaped, like a snow-plough, with reversible ends; and sketches with details are given of two other kinds of small scrapers, which are said to be more effective than the buck-scraper, when the lead is over 150 feet.

As regards cost, complete details are given for the work done in November, 1882—viz., 55,600 cubic yards, excavated and tipped, at a total cost of £693, or at the rate of about 3*d.* per cubic yard, the contract price being 5½*d.* for this particular section, but in some sections it was 4½*d.* per cubic yard.

W. H. E.

Floating Landing-Stages. By Ludwig Schrader.

(Zeitschrift des Architeckten-und Ingenieur-Vereins zu Hannover, vol. xxix., 1883, p. 465.)

After stating the objects for which floating landing-stages are constructed, the circumstances which generally determine the site for such structures, the desirability of so constructing them as to admit of their ready extension to meet the conditions of increased traffic, and other particulars, the Author gives the following details of construction of a stage 820 feet long by 82 feet wide, connected with the shore by four movable bridges, whose length is determined by the condition that at lowest water-level the slope should not exceed 1 in 15.

The stage rests on forty-two floating iron boxes, each 82 feet long, 13 feet 1½ inch wide, and 4 feet 11 inches high, placed at clear intervals of 6½ feet apart. On these rest five box-girders, also 4 feet 11 inches deep, extending over the whole length of the stage, and so connected with the floating girders below that any one of these can be easily taken out for repair. These box-girders carry joists formed of double balks, about 9 inches by 12 inches

and 12 inches by 12 inches respectively, bolted together, placed at intervals of 3·9 feet from centre to centre, and notched into the box-girders. Over these is a double layer of planking, the top layer being calked watertight. Each floating box is divided into four watertight compartments by three diaphragms, and is built up of strong top, bottom, and side plates, strengthened and stiffened in the usual manner.

The weight of the entire landing-stage is about 2,300 tons, and, as the surface of each of the floating girders is 1,076 square feet, this gives a depth of immersion of 1 foot 9¼ inches.

For smaller landing-stages for passenger traffic the cover-plates of the floating girders can be used as a flooring.

The Paper closes with the computation of depth of immersion of a small landing-stage, 59 feet long and 23 feet broad, formed in two steps, with treads of 12½ feet and 10½ feet respectively, the river end being about 4 feet high, and the shore end 2½ feet. The rise and fall of tide is 23 feet, and the bridge (82 feet by 14 feet) connecting the stage with the shore so arranged that at low water it rests on it at a distance of 5¼ feet from the shore end, and at high water at 2 feet 9½ inches from the centre of the stage. The top of the staging is asphalted, and the sides are covered and protected by a plank-facing. The dead weight of the staging complete (that is, including plank-facing, asphalt, &c.) is assumed to be about 30 tons; that of the bridge also 30 tons (half of which rests on the staging) and the movable or live load 61½ lbs. per square foot.

The calculation of the depth of immersion of the floating-stage being a simple hydrostatic problem, details are unnecessary, but the results are as follow :—

Depth of immersion of floating stage when fully loaded = 27¼ inches.
„ „ due to dead weight alone . . = 11¼ „

In the above computation the weight of the plank-facing (about ½ ton) has not been considered. Allowing for this, the position of the centre of gravity would be shifted nearly 7 inches towards the river end of the stage, where the depth of immersion would be 9½ inches, and at the shore end 8½ inches.

Assuming the bridge to be resting on the floating-stage at 5¼ feet from the shore end as at low water, and fully loaded, the dead weight of the stage alone being considered, the effect would be to shift the position of the centre of gravity 2¼ feet towards the shore end, which would be immersed to a depth of 1½ foot, and at the river end 14 inches. With the staging also bearing a live load of 61½ lbs. per square foot, the depth of immersion at the shore side would be 2½ feet, and at the river side 2 feet 1½ inch, or a slope of 1 in 75.

W. H. E.

The Improvement of the River Weser.

By — Franzius.

(Deutsche Bauzeitung, 1883, p. 181.)

The works comprised in this improvement will take six years to complete, and will be carried out in the following order: viz., in the first two years the closing of three subsidiary channels, or branches (caused by the Haerier sandbank and the Strohhaus and Dedesdorf shoals), and the widening of the river proper in its narrower places will be accomplished; in the next two years, the construction of training-dams and the general widening of the river at low-water section; and during the last two years the regular formation of the entire bed of the river.

As a type of the works necessary for closing the branches, that of the widest and deepest, namely, the "Strohhaus," is taken. This branch is 2½ miles long, about 490 yards wide at high-water, and 380 yards at low-water level, with maximum depths of 33 feet and 23 feet respectively. The dam to close this branch will be formed of cribwork, each block or mattrass containing 260 cubic yards, and about one hundred and fifty of these will be required. They will be made on the river bank, floated out and sunk *in situ*, and in the first year the dam will be thus built up to low-water level, where it will have a top breadth of about 40 feet, with side slopes 1 to 1. During the second year the dam will be carried up to its projected height, and built of rubble-stone; the other two dams will be completed simultaneously, and in the same manner; and the widening of the narrower parts of the river proper will be carried out.

The two branches of the river formed by the Strohhaus shoal have a total mean sectional area of 7,176 square yards; and, as the average discharge is 3,924 cubic yards per second, the mean velocity is therefore $\frac{3,924}{7,176} = 0 \cdot 54$ yard $= 1 \cdot 64$ foot per second. By closing the Strohhaus branch the section is reduced to two-thirds of the original area; the velocity will be therefore proportionately increased to about 2½ feet per second. The bed of the river being loose sand, this increased velocity will in time so deepen the bed as to restore the original regimen. Dredging would also be employed in certain selected places, to assist in bringing about this condition of things.

The training-dams have a total length of 15½ miles, and, as before said, will be built in the third and fourth years; they serve to regulate the course of the river, and act in deepening the bed. About 43 million cubic yards of material have to be removed, two-fifths of which, it is considered, may be moved by the influence of the tides alone.

The earthwork is of two kinds; either digging out the soil dry and transporting it where required for raising the surface, or else

by dredging out below low-water level and removing the material in hopper barges, and depositing it in the closed branches. As the surfaces are being raised machinery will be employed to lift the material dredged out, or it will be so mixed with water as to allow of its being forced through pipes where necessary. It is pointed out that the economical and efficient management of these operations will require great technical skill and judgment, so as to utilize at the right place and at the right time the full action of the tides. W. H. E.

Beaufort West Dam. By A. B. Brand.

(Transactions of the South African Philosophical Society, Cape Times, 5th June, 1883.)

The Karoo is traversed by numerous Greenstone dykes, which, under-ground, form walls or natural dams, and above-ground stand out as ridges; where breaks occur in these ridges, the construction of an embankment will often convert a part of the district above into a large reservoir. The town of Beaufort West was originally laid off immediately below a break of this kind. Before the dam was constructed, the town was dependent upon two springs which came to the surface at the break in the dyke. The joint yield of these springs varied from 26,000 gallons per day in dry years, to 99,000 gallons in wet years. The droughts here are periodical, and are sometimes so severe as to destroy the crops and even fruit-trees. The springs become weak on such occasions.

As Beaufort West is situated centrally on the main road from Capetown to the Free State, Transvaal, and the interior, large demands are made upon it for forage, water, and other supplies. To meet these an increased water-supply for irrigation and domestic purposes was necessary.

At first three schemes were proposed: (1.) The lowering of the dyke forming the natural dam. (2.) The construction of a weir immediately above the springs, so that the flow of the water over it should scour out the deposit of silt which had formed in a small dam surrounding the springs. (3.) The raising of the water from the natural dam by an Archimedean screw. The first scheme was not attempted; the first flood carried off the weir formed in the second case, and the expense of the third soon led to its abandonment.

A series of droughts having occurred for some years after 1860, the Municipal Commissioners commenced the construction of an earthen embankment above the line of the Greenstone dyke, without calling in any professional adviser. The water began to flow into the reservoir in December, 1867. When the water had reached a height of 10 feet against the made bank, considerable leakage appeared at the base. As this leakage increased, the Author was instructed to report upon the stability of the bank, and the best means for placing its safety beyond a doubt. He found that the drainage area was 60 square miles, and the storage

capacity of the reservoir when full 500,000,000 gallons. On taking cross-sections of the six feeders, it was found that their capacity for discharge agreed with that previously found for the river, namely, 68,333,000 gallons an hour, or, allowing for extraordinary floods, 83,333,000 gallons an hour—a flow that would fill the reservoir in six hours. There were two overflows to the reservoir, the joint discharging capacity of which was scarcely sufficient for the flow of the smallest feeder.

The embankment had an inner slope of 2 to 1 at the highest part, and an outer slope of 1 to 1. The width at top was 3 feet. An examination of the embankment disclosed several large fissures along the face of the bank, and oblique cracks at the joints in the layers of the earthwork. No foundation trench had been excavated, and no surface soil had been removed. A naked pipe had been placed through the embankment, and a permanent spring had been banked over in the river-bed without any provision having been made for carrying off the water.

The Author reported that the dam was in a dangerous condition, but his arguments failed to convince the Municipal Commissioners.

On the 22nd of October, 1869, a heavy thunderstorm broke over the drainage area—a rain-gauge registered 3·05 inches in thirteen hours. On the 23rd, when the water had reached to 5 feet from the top of the bank, the reservoir burst, destroying £30,000 to £50,000 of house property, but drowning no one, as the townspeople had been ordered to remove.

There was nothing done towards the repairing of the dam until 1874, when the Municipality resolved to carry out a scheme proposed by the Author. This scheme consisted in keeping the level of the overflow the same as before, viz., to give 19 feet of water against the bank at the deepest point, but to widen both the overflows. The main overflow was made 6 inches lower than the smaller one. The inner slope of the embankment to be made 3 to 1, and pitched; the outer slope to be 2 to 1. The top of the embankment to be 10 feet above the sill of the main overflow, and its width to be 10 feet. A puddle core was also proposed for the new portion of the bank. In 1875, Mr. J. G. Gamble, M.Inst.C.E., the hydraulic engineer to the Colony, visited the site of the work, and recommended that the whole of the embankment be puddled, and that siphons be adopted for drawing off the water.

In removing portions of the old bank, and in joining the new work into the old, the defects of the old work became apparent. These are described in detail in the Paper.

The first run of water into the repaired reservoirs took place in October, 1877, but the dam was not filled to the overflows until January, 1879. From the 1st to the 13th of March 1879, the greatest fall of rain took place which has ever been recorded in this locality. Rain fell continuously for thirty-eight hours; a gauge registered 6 inches in this time, 3·15 inches of which fell during the first ten hours. On the 19th, although the feeding-

streams were all overflowing their banks, the discharge at the main outlet did not exceed 4½ feet in depth. On this day the water-level rose another 2 feet in forty minutes, caused by the bursting of three dams in the same drainage area. To provide against danger from this source in future, the overflows were increased in width, and the top of the embankment raised another 2½ feet throughout. The top line falls slightly from the highest part of the embankment to the lowest, so that, should the water overtop the bank, the less expensive part will go first.

The works were completed in February, 1880, at a cost of £13,800, including £3,300 for the cost of the original dam.

The direct revenue derived at present from the leased erven[1] amounts to £1,000 a year, but the indirect benefit to the town in having an important addition to the otherwise scanty supply, is much greater and more important than the direct revenue.

T. S.

The Cost of the Suez Canal.

(Bulletin décadaire du Canal Maritime de Suez, Nos. 1 to 412.)

Accounts of the expenditure on the Suez Canal, as approved by the General Assembly of the Shareholders year by year, from 1870 to 1882, are contained in the "Bulletin décadaire du Canal de Suez." The accounts are drawn up in the same form (with one exception) year by year. They comprise, first, the Inventaire Général de L'Actif et du Passif, which corresponds, to some extent, to the capital accounts of the English railway companies. Secondly come the Comptes de l'Exercise, corresponding to gross and net revenue accounts. And, in the third place, there is a statement of the receipts or profits realised by the Company during the execution of the Canal, which is a peculiar feature in these accounts. It is intended to give as brief an abstract of these accounts as is consistent with clearness.

On the 31st of December, 1869, forty-four days after the opening of the Canal, the Prix de revient, or cost-price, is stated in the supplement to the "Bulletin décadaire," No. 22, as follows (in abstract):—

	£.
General expenses of the constitution of the company.	119,660
Cost of negociation, commission, stamps, and expenses as to shares	441,720
Cost of management for eleven years	567,300
Interest during construction, including sinking fund.	3,316,520
Services of health, telegraph, domain, and transit, 1868–69	533,530
Cost of construction, including sinking fund to pay for materials	11,654,223
Total	£16,632,953

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[1] *Sic* in original.

No further details of the cost of construction are given in the Bulletin; but in a summary of the expenditure down to the opening, which is quoted by Mr. Knight, in the "Practical Dictionary of Mechanics," p. 438, and which amounts to about £550,000 less than the above sum, dredging machines, heavy plant and workshops, are set down at £2,251,000, and material for transport service at £329,000, leaving the cost of the Canal works £87,068 per mile.

The "Compte Général" for the 31st of December, 1869, contains, in addition to the details above summarised, which do not again appear in the accounts, six items of "Estimated Assets," viz.:—

	£.
Office buildings and furniture	41,081
Domain	191,272
Transit	8,971
Maintenance (materials)	275,612
Telegraph	1,894
Water service	216,652

These items reappear, with slight alterations, in each of the Inventaires, amounting to a maximum of £871,821 in 1874, and falling to £672,836 in 1882. Whether the payment for them is comprehended in the "Prix de revient" is not clear.

A third item of assets in the "Compte Général" is cash and securities in hand, and debts receivable, amounting to £833,468.

Against this statement of assets, amounting in all to £18,145,784, the Passif, or debit account, is as follows:—

	£.
Social capital, 40,000 shares at £20	8,000,000
Loan, 333,333 bonds of £12	3,999,996
Various creditors	282,584
Difference in favour of assets	5,863,204
Total	18,145,784

In the "Inventaire ou Compte Général" for each year succeeding 1869, the items of the "Prix de revient," the Act if suivant estimation, or estimated assets, and the "Actif disponible ou réalisable," or cash in hand, are severally stated, and no further distribution of the annual expenditure on capital is given. A sum is added, in each inventaire, to the "Prix de revient" consisting of expenses incurred for the completion, enlargement, or improvement of the canal, together with the balance of charges against the first establishment. By 31 December, 1882, the "Compte Général" was as follows:—

Cr.	£.
Cost price of Canal to 31st Dec. 1882	19,335,278
Estimated assets	672,836
Disposable assets	1,997,934
	£22,006,048

The Passif, or Dr. side of the account, is as follows:—

	£.	£.
Social capital, 400,000 shares . .	8,000,000	
Consolidated arrears of interest .	1,360,000	
Loan of 1867–68	3,999,996	
„ 1871	480,000	
„ 1880	162,486	
		14,002,482
Various creditors	760,208	
Reserve fund	223,072	
		983,280
Total, &c. . .	..	14,985,763
Coupons not presented and sinking fund for *délégations* . .	..	169,598
PROFIT AND LOSS—		
Net profit, &c., 1882	1,266,972	
Paid on account.	450,704	
Balance		816,268
Difference in favour of the actif .	..	6,034,417
Total	..	22,006,046

The statement of the receipts or profits realised by the Company, and applied to the construction or improvement of the Canal, attached to the Inventaire Général of the 31st of December, 1882, is as follows (in abstract):—

1. DURING THE EXECUTION OF THE CANAL.

	£.	£.
Receipts prior to the constitution of the company	..	260
Indemnity paid to the Viceroy by award of 1864	..	3,360,000
Ditto by convention of 23rd April, 1869	1,200,000	
Less for buildings at Damietta .	10,217	1,189,783
Produce of funds (interest) .	..	804,141
Produce of sales of land—		
Cession of Wady	400,000	
Fees paid	96,266	
	303,734	
Various lands	2,203	
		305,937
Sundry receipts	..	274,540
		5,934,661

2. DURING THE PERIOD OF WORKING.

Sundry receipts	..	99,756
Total .	..	6,034,417

It is noted in the Inventaire Général for the 31st of December, 1882, that 2,851 shares; 19,975 consolidated *bons* for arrears of interest (at £3 8*s.* each); 32,255 of the £12 bonds, and 20,285 of the £4 bonds of 1871, have been paid off by the Sinking Fund.

F. R. C.

The Traffic and Earnings of the Suez Canal.

(Bulletin décadaire du Canal Maritime de Suez, Nos. 1 to 412.)

From the opening of the Suez Canal, on the 17th of November, 1869, to the 31st of December, 1882, the maritime movement through it has been as follows:—

Year.	Ships.	Tons.
1870	486	435,911
1871	765	761,467
1872	1,082	1,439,169
1873	1,173	2,085,072
1874	1,264	2,423,672
1875	1,494	2,940,708
1876	1,457	3,072,107
1877	1,663	3,418,949
1878	1,593	3,291,535
1879	1,477	3,236,942
1880	2,026	4,344,519
1881	2,727	5,794,401
1882	3,198	7,122,125

The receipts from the navigation have been as under:—

Year.	£.
1870	206,372
1871	359,749
1872	656,303
1873	885,892
1874	994,375
1875	1,155,452
1876	1,198,999
1877	1,310,973
1878	1,243,928
1879	1,187,440
1880	1,593,617
1881	2,050,974
1882	2,421,834

The above figures appear in all the annual reports from 1877 onwards. Down to that date the tonnage of 1870 was returned at 654,915 tons of "real capacity"; that of 1871 at 761,467 tons; and that of 1872 at 1,744,481 tons. From 1877 the tonnage is specified as *tonnage brut*, or gross tonnage. The difference is connected with a long dispute, which was only settled by the threat of military intervention on the part of the Porte, as to the mode of charging tolls.

Of the 3,198 vessels that passed through the Canal in 1882, 1,610 arrived by the Mediterranean, and 1,588 by the Red Sea.

2,361	were	commercial steamers.
501	„	postal „
134	„	freighted by H.M. government.
154	„	ships of war.
10	„	yachts.
1	„	"citerne" (tank vessel).
37	„	tugs.

It will be seen, from a comparison of the tonnage with the number of vessels, that the average size of the ships passing through the canal has more than doubled since its opening. In 1870 the average tonnage was 897 tons per vessel; in 1875 it was 1,970; in 1880, 2,144, and in 1882, 2,227 tons.

From the opening of the canal the total expenses of administration and of working, including maintenance, have averaged £233,000 per annum. Interest of money during construction, amounting to £3,316,520, has been carried to capital account. Since the opening, the interest on borrowed money, which is treated as the first social charge, has amounted to about £460,000 per annum.

For the first three years after the opening the expenses of all kinds exceeded the receipts. In 1873, £200,000, and in 1874, £400,000, were divided among the shareholders, and the arrears of interest were in this later year consolidated, *bons*, or warrants for the same, on which interest has subsequently been paid, being then distributed.

From 1874 the profits have increased. In 1875 £500,000 were distributed among the shareholders; £6,370 were paid to the Egyptian Government; and £5,944 were divided among the founders, administrators, and employés, as their 14 per cent. of the profits. In 1882 the shareholders received £1,371,500 (or rather this sum was carried to the credit of the shares); the Egyptian Government received £190,044, and the founders, administrators, and employés (in addition to their salaries and allowances) received the sum of £177,376.

The total sum distributed among the shareholders (as before qualified) since the opening of the canal, to December, 1882, had amounted to £6,714,000, which is equal to an average dividend of 6·45 per cent. per annum, with a slight rebate for compound interest owing to the irregularity of the payments. The Egyptian Government have received £495,000, and the founders, administrators, and employés (who appear from the "Compte Général" to have contributed £260 towards the capital of £22,000,000) have received £462,000.

The coupons for twenty-five years have been detached from the 176,602 shares now in possession of the British Government, in order to secure the payment of a sum of £1,200,000, with interest at 10 per cent. per annum, which, by an agreement dated 23rd of April, 1869, the Viceroy of Egypt undertook to pay to the Canal

Company, in consideration, among other things, of their renouncing "any exception, faculty, or special privilege." On the security of these coupons, certain stock was issued, under the name of *délégations*, but the operation was not regarded as a social charge on the company. The sum which the holders of these shares would have received, up to the end of last year, amounts to £2,536,000, and there are still twelve years for which the coupons have been detached. Thus the shareholders in full enjoyment of their rights are not more than 56 per cent. of the proprietors of the canal.

The amount of dredging and excavation required for keeping open the Canal and the Roads of Pelusium have been as follow:—

	Cubic metres.
Dredging from Canal	7,507,918
" " port	5,470,087
Excavation of slopes	626,975
Enlargement of Canal and basins	1,788,489

giving a total of 15,393,469 cubic metres, or 20,140,040 cubic yards.

The most rapid passages recorded through the Canal were those of H.M.S. "Warrior," and of the "Hebe," in 1870; the former in twelve hours fifty minutes, the latter in twelve hours ten minutes. From 1876 a return is made of the average length of passage, distinguishing the time for which the vessels were in actual motion, and the total time spent in the Canal. The former averaged from seventeen hours to seventeen hours thirty minutes from 1876 to 1880. In 1881 it was eighteen hours sixteen minutes, and in 1882 eighteen hours fifty-nine minutes. The time spent in the Canal by each vessel rose from thirty-nine hours in 1876 to forty-one hours in 1880. In 1881 it was forty-five hours fifty-three minutes, and in 1882 fifty-three hours forty-six minutes. The relation between the number and size of the vessels, and the time occupied in transit, will be seen from the following table:—

Year.	Mean Tonnage.	Number of Vessels.	Time in Motion.		Time in Canal.	
			Hrs.	Min.	Hrs.	Min.
1876	2,108	1,457	17	0	39	0
1877	2,056	1,663	17	30	40	24
1878	2,066	1,593	17	15	40	10
1879	2,191	1,477	17	12	40	30
1880	2,144	2,026	17	10	41	0
1881	2,124	2,727	18	16	45	53
1882	2,227	3,198	18	57	53	46

F. R. C.

On the Preservation and Use of Beech-wood for Railway Sleepers.

By — Claus.

(Dingler's Journal, vol. ccxlix., 1883, p. 183.)

The use of railway sleepers of beech-wood has hitherto been very limited. In Germany only about 1 per cent. of the sleepers is of this wood, and in Austria 3 per cent., although large beech forests are available in both countries. The slight durability of ordinary beech sleepers is the chief reason of this; their life is reckoned at two and a half to three years, while oak will last fourteen to sixteen, and fir seven to eight years. The best method of preserving beech sleepers appears to be impregnation with creosote. Prepared in this way the average durability of the wood for railway purposes appears to be about eighteen years, while chloride of zinc only preserves it for fifteen years. Sleepers impregnated with sulphate of copper or sulphate of barium had to be replaced after four or five years. In many places the expense of impregnated beech-wood is so much less than that of oak, that it might be used with great advantage were it not for the peculiar manner in which some beech sleepers have been observed to give way under sudden strain. In such cases the exterior of the wood appears perfectly sound, while the heart has become rotten and affords no hold for spikes or bolts.

In France the proportion of beech sleepers is much larger than in Germany; they are chiefly impregnated by Blyth's method, by which each sleeper absorbs about 22 lbs. oil of tar, while in Germany 36 lbs. of creosote are injected. The French method does not appear to remove the organic matters, which are liable to decomposition.

In Germany Rütger's method is in use for preparing these sleepers. They are gradually raised to a temperature of 130° Centigrade, and dried for at least four hours, until they cease to give off vapour and are completely warmed throughout. They are then removed, on the same trucks upon which they have been dried, to the creosoting apparatus. This consists of a horizontal cylinder with hermetically closed doors in which a partial vacuum is produced and maintained for half an hour. The warm creosote is then allowed to enter the cylinder, and the whole is subjected to a pressure of 100 lbs. per square inch for one hour. Before injecting the creosote it is advisable to extract by boiling so much of the sap from the timber as is possible. This should be done while the wood is new and before the sap has begun to ferment. After this operation the sleepers must be allowed to dry for two or three months. Beechwood prepared in the above manner appears to be well suited for railway sleepers.

W. F. R.

Notes upon the Iron Bridges on the Grand Ceinture Railway, Paris. By — Geoffroy.

(Annales des Ponts et Chaussées, 1883, p. 440.)

This railway is 48¼ miles long, and comprises two hundred and thirty-four works of masonry and fifty-five iron bridges. Among the latter are thirty-eight railway bridges, mostly for two lines, and seventeen road bridges, varying in width between 13 feet and 42 feet. These works were executed, including erection and painting, for 39 francs per 100 kilograms of wrought iron, 26 francs per 100 kilograms of cast iron, and 130 francs per cubic metre of timber (say £15 12*s.* per ton, £10 8*s.* per ton, and 20*s.* 11*d.* per cubic foot). The price of ironwork of eight bridges, partially on account of the erection being carried on without interruption of traffic, was 49 francs and 32 francs respectively.

Under-Bridges.—In eight bridges, with spans of from 3 to 6·74 metres (10 feet to 22 feet), the rail-bearers, which are placed immediately under the longitudinal sleeper, act as main-girders, and are laterally connected with plate- or lattice-frames. The same construction has been adopted in four other cases of bridges of 7 to 11 metres spans, where ample headway exists for the roads beneath them. In all other cases the distance between the top of the rail and the bottom of the structure, *i.e.*, the thickness of the structure, had to be kept small. The practically smallest dimension of this distance would be 0·32 metre (12·5 inches). The smallest carried out is 0·35 metre, and has been obtained by placing a longitudinal girder at each side of the rail, not less than 0·40 metre apart, forming a kind of trough, but as the tops of these girders may not project above the top of the rail, and, consequently, their depth is limited to 0·32 metre or 0·35 metre, the greatest distance spanned in this way is 5 metres. Beyond that distance the thickness of the structure had to be increased; the next type therefore shows troughs of an increased depth, the distance between the girders being 0·55 metre and 0·65 metre. A thickness of the structure of 0·50 metre admits of the construction of cross-girders between the main girders 2·11 metres or 2·7 metres apart, with a depth of 0·50 metre. In two cases this dimension is the depth of an arch at its crown. The arches referred to have spans of 21·6 and 28·0 metres respectively, while girders of that depth are not constructed of spans larger than 10 metres. With a thickness of 0·60 metre the cross-girders can have a depth of 0·35 metre, which is sufficient to place the main-girders with a clear space between them of 4·30 metres. The depth of the main-girders is then no longer limited. A bridge for one line of rails, constructed according to this type, has about 19 metres span, with a depth of girders of 2·1 metres. With a thickness of 0·67 metre, and a depth of cross-girders of 0·40 metre, a bridge for two lines of rails and a span of 25 metres has been constructed on the same principle. There are also continuous-girder bridges of two, three, and five

openings, resting on cast-iron columns, the largest spans being 15·34 metres.

According to an abstract on page 547, the weight of iron in the double-line bridges varies between 651 and 3,571 kilograms per lineal metre.

Over-Bridges.—These bridges are constructed according to two principal types. In the one type the plates and the concrete or granite pavement are carried on cross-girders, which are supported by main-girders not more than 7 metres apart; the minimum distance between the top of the roadway and the bottom of the girders, *i.e.*, the thickness of the structure, is 0·65 metre. This type is used for spans of from 8 to 20 metres. In the other type the main-girders are beneath the roadway material, and the thickness of the structure is at least 1 metre, the smallest span being 7·8 metres. This type is used for widths of roadway of from 6 to 13 metres. The cost of the latter type is from 60 to 90 francs per square metre (41·81*s.* to 62·72*s.* per square yard), while that of the former is from 102 to 110 francs.

One of the road bridges has a length of 100·5 metres in seven spans, supported on columns, and a width of 10 metres. On page 556 is a Table containing dimensions and other data of some of the principal structures of this class, while the detailed description of the fifty-five bridges occupies 120 pages and 3 plates.

M. A. E.

Self-Recording Apparatus for Testing Iron Girders.

By G. B. Biadego.

(L'Ingegneria Civile e le Arti Industriali, May 1883, p. 70.)

This Paper describes the Author's apparatus for registering the deflection of a girder under dead and moving loads. To the lower flange of the girder a brass stile is attached by means of a vice; this stile projects from the side of the girder. On a scaffold, independent of the bridge, is placed a tripod carrying a recording paper, placed so that the stile shall touch it. The paper is carried on revolving drums, which are turned by clockwork at uniform speed. If a train passes over the girder, when the instrument is properly adjusted, a line is drawn upon the paper indicating the motion of the point of the girder at which it is fixed. It can be placed so as to show either the vertical or horizontal oscillations of the girder, or two instruments can be applied at the same time, one to record the vertical, the other the horizontal movements; for the latter the paper may be fixed instead of revolving.

The instrument was used in testing a bridge of three continuous spans of 263, 312, and 263 feet. Drawings are given showing the curves described by the stile under several conditions of loading. Drawings of the apparatus are also given.

W. H. T.

Heat encountered in Tunnelling through High Mountains.[1]

By E. STOCKALPER.

Believing it is this question of the heat to be encountered which must really decide the choice between the competing projects for long tunnels through Mont Blanc and the Simplon, the Author summarises the knowledge that has now been acquired, and applies it to a comparison of the two proposals. At the outset he pays a high tribute to the value of the information contributed and the investigations conducted by Dr. Stapff,[2] the engineering geologist of the St. Gothard Railway. After reviewing the effects of a high temperature upon the workmen and upon the progress and cost of the work, he alludes to the limit at which a tunnel would become too hot to work in; estimates the temperatures likely to be met with in the Simplon and Mont Blanc tunnels, at various points along their length; and considers the best means of ventilating and cooling them during construction.

The method which he himself recommends, for tunnelling through the Simplon or other high mountains, is to extend the drivage from each entrance to as great a distance into the mountain as can be done without the heat becoming so excessive as to interfere too seriously with the work; and then to sink from the surface an inclined upcast air-shaft, underlying forwards to join the tunnel at the furthest point reached, whereby efficient ventilation would so far be obtained. From the junction the work would be pushed forwards by driving simultaneously both a bottom heading and a top heading, the latter alone being in communication with the shaft. The two headings would be kept continuously ventilated pretty close up to the end or forebreast, by holing successive rises or communications between them: so that the current of fresh air entering from the tunnel-mouth should flow forwards along the whole length of the bottom heading, pass up through the furthest rise, travel back along the top heading, and be drawn up the inclined shaft by an exhausting ventilator at top. The enlargement of the tunnel to its full final section would be completed from the entrance to the junction with the shaft; beyond the shaft it would not be continued until after the headings had met from the opposite sides of the mountain. But meanwhile the top heading would be enlarged to the full arch of the tunnel roof, which would also be lined with masonry; leaving only the enlargement of the bottom heading, and the building of the side walls, to be completed afterwards. The size of the upcast shaft should be not less than 13 feet by 10 feet; and its inclination is sketched at about 45°, so as to render it serviceable also in directing the head-

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[1] "Les grands tunnels alpins et la chaleur souterraine." Lausanne, 1883. 4to. 32 pages, 3 plates. The original is in the Library of the Institution.

[2] Minutes of Proceedings Inst. C.E., vol. lxii., pp. 399–407. See also vol. lxiii., pp. 380–382; vol. lxiv., pp. 390–397; and vol. lxxii., pp. 373–376.

ings along the true line of the tunnel for ensuring their meeting correctly.

Owing to the heat in the St. Gothard tunnel, the conditions under which the work was there carried on reached nearly the limit of feasibility; from the time of the headings meeting to the completion of the tunnel, the cooling produced by the ventilation did not exceed $\frac{1}{2}$° C. or 1° F.; and the tendency of the air to get saturated with moisture continued almost the same on the completion of the work as during its progress. On the other hand, the places where the work was being done by compressed air were thereby cooled down fully 2° C. or 4° F. below the temperature of the rock; and after the headings had met, the through current of ventilation, averaging 750 cubic metres, or 26,000 cubic feet per minute, materially facilitated the work. By the method which he recommends, the Author considers a tunnel can be successfully driven through rock hotter by 5° or 6° C. = 9° or 10° F., than was met with in the St. Gothard tunnel. In the Simplon tunnel the maximum temperature would not exceed about 36° C. = 97° F.; in this respect therefore the conditions would be analogous to those already dealt with in the St. Gothard tunnel. But in the proposed Mont Blanc tunnel the temperature would rise as high as about 53° C. = 127° F., rendering the feasibility of the work very questionable.

A. B.

Preventing Waste of Water. By Thomas J. Bell.

(Ohio Mechanics' Institute, June, 1883, pp. 51–66.)

The Author enumerates five methods as now employed for perventing waste of water; and refers more particularly to the water-works of Cincinnati, where the supply had previously been too lavish, and where also the combined transverse sectional area of the main supply-pipes is less than 18 per cent. of that of the various branches leading off from them. Firstly, house-to-house or day inspection is used with varying results by all water-works. Secondly, meters are the most reliable means of checking waste, though their universal adoption in the near future seems not likely; in Providence, R.I., where about half the service-branches have meters attached, the daily consumption in 1880 was only about 30 gallons per head. Thirdly, the licensing of plumbers, and the regulation of their work, have largely contributed to prevention of waste in England, but are not yet enforced in America. Fourthly, the Deacon waste-water meter[1] has been in successful operation in Liverpool, where it was first introduced. Fifthly, the Bell waterphone, which has been a year in use in Cincinnati, has proved most highly successful and satisfactory. It consists of a

[1] Minutes of Proceedings Inst. C.E., vol. xlii., p. 143.

metallic diaphragm at one end of a steel rod, the whole being enclosed within a trumpet-like casing of gutta-percha. When attached to a water-pipe, it magnifies to such a degree the wave-sounds of flowing water that the minute current produced by a mere drip is at once detected. The method of using this instrument in Cincinnati is described in detail; and the immediate result of its use there has been that—whereas in 1881 the gross daily consumption was 87·0 gallons per head, of which 45·6 gallons were wasted—in 1882, with an increase in the legitimate consumption, the gross consumption had fallen to 69·7 gallons, of which only 24·3 gallons were wasted.

A. B.

Oesten's Waste-Water Indicator.

(Journal für Gasbeleuchtung, 1883, p. 327.)

This invention is designed to meet the want of some means of detecting the wasteful consumption of water resulting from unsound valves and stop-cocks, as well as leakages in house service-pipes.

The apparatus is described as follows:—That portion of it immediately connected with the service-pipe consists of a valve-casing and valve, through which the current of water passes. Above the valve-casing is fixed a cylindrical vessel in which works a piston, which is raised by the water until an opening at the side of the cylinder becomes exposed. Through this opening the water flows into the supply-pipe. From the piston a rod passes up watertight through the top of the cylinder, and is weighted to give a constant pressure equal to a column of water 1½ metre (5 feet) high. When a tap is opened in the house, the pressure on the piston is reduced, and the piston rises until the outlet at the side of the cylinder is partly opened. The water now passes through this opening, and causes a loss of pressure equal to the constant pressure on the piston, by which equilibrium is maintained. From the constant pressure results a constant velocity through the opening; hence the quantity of water flowing corresponds to the position of the piston, and this position is shown by a pointer attached to the weight on the piston-rod, and indicating on a scale outside the cylinder. When the outlet is uncovered for one-fourth of its height, 2,000 litres per hour are passing; with half the opening exposed, 5,000 litres pass per hour; with three-quarters open, 8,000 litres are delivered, and when the whole outlet is opened the quantity of water flowing equals 10,000 litres per hour.

In order to make the apparatus sensitive enough to indicate the smallest quantities, the piston moves below the outlet-opening for a considerable distance until it finds a resting-place on the bottom of the cylinder. From this point the piston will commence to rise with the least dropping of water from the supply-pipe, and will

rise until its lower edge is level with that of the outlet-opening. This length of stroke is transferred by means of a pneumatic tube to another indicating appliance. The weight in rising presses against an india-rubber ball, which is connected to an indicating vessel by a tube of small diameter. The pressure on the air in the ball and tube drives a coloured fluid from an opaque into a transparent tube, and its appearance in the latter indicates that the piston has arrived at the point where the outlet commences to be opened. The area of the tube being many times less that of the cylinder in which the piston works, causes the ascent of the latter to be multiplied, so that the slightest difference in level may be clearly indicated, and the passage of small quantities of water determined.

G. E. S.

On the Cycle of Operations of Gas-Engines. By A. Witz.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. xcvi., 1883, p. 1310.)

All the gas-engines so far constructed may be placed in four distinct groups:—

1. Explosive gas-engines without compression.
2. Explosive gas-engines with compression.
3. Combustion-engines with compression.
4. Atmospheric motors.

In all these various types, the series of transformations of the gaseous mixture constitutes a closed cycle, for it may be admitted that the fluid returns to its natural state after it has been burnt in the cylinder; the combustion produces a radical modification of the molecular grouping; combinations have taken place which have taken up the potential energy of the combustible and combining gas, but the mass of the fluid employed has not changed; the total specific heat has only undergone an insensible variation, whilst the condensation does not exceed 2 per cent. of the volume; it may therefore be admitted that in the explosion or combustion there is only produced a variation of the temperature, volume and pressure. In the expansion, a portion of the heat is transformed into work; the rest is carried to the refrigerator, and the gas returns to its initial state.

The cycle admits of calculation; it presents remarkable but simple forms, when the portions of equal stroke are neglected, which correspond in the preliminary period of admission under constant pressure, and of compression under the same pressure in the period of expulsion. Those lines which superpose are in a way foreign to the cycle, as the compression gives back in sum the heat absorbed in admission.

The cycle of the four types is formed of adiabatic lines, and lines parallel to the axes of volumes and pressures. Let it be assumed that the explosion is instantaneous; the gas is heated under con-

stant volumes, except in the combustion-engines, in which the gas changes temperature under constant pressure. The first and second types furnish a diagram which does not correspond to that of any hot-air engine; the third and fourth type reproduce the cycles of the engines of Ericsson and Stirling.

The economic coefficient of each type ρ is given in the following formulas, in which t represents the initial temperature of the mixture; T the temperature of explosion or combustion; θ the temperature produced by the preliminary compression following an adiabatic curve; t' the temperature at the end of the expansion, and γ the ratio of the specific heats:—

First type . . . . . . $\rho = 1 - \gamma \dfrac{t' - t}{T - t}$

Second type . . . . . . $\rho = 1 - \gamma \dfrac{t' - t}{T - \theta}$

Third type . . . . . . $\rho = 1 - \dfrac{t' - t}{T - \theta} = 1 - \dfrac{t}{\theta}$

Fourth type . . . . . . $\rho = 1 - \dfrac{t' - t''}{T - t} = 1 - \dfrac{t''}{t}$

In the last formula, t'' is the temperature to which the refrigerator lowers the temperature of the gases, after they have been expanded below atmospheric pressure.

In discussing these formulas, it is seen that for the second type $T - \theta$ is sensibly equal to $T - t$, whilst $t'' - t'$ is less than for the first type; in fact, in the compression-engines, $\dfrac{t'}{t} = \left(\dfrac{T}{\theta}\right)\dfrac{1}{\gamma}$; whilst for non-compression engines, $\dfrac{t'}{t} = \left(\dfrac{T}{t}\right)\dfrac{1}{\gamma}$; whence it results that the yield of these engines is less; practice has long proved this to be so.

The economic coefficient of the third type presents the peculiarity of being independent of T; but the yield diminishes as the effectual work of the machine increases, for θ differs more and more from T. Compared with the second type, these motors appear less advantageous, for $t' - t$ has become greater; in fact, $\dfrac{t'}{t} = \dfrac{T}{\theta}$; on the other hand, $T - \theta$ has slightly diminished, on account of the difference of the two specific heats at constant volume and constant pressure.

To better appreciate the relative value of the three cycles, let there be chosen two values of T and t, between which the series of operations may be carried out. If $T = 573$ absolute, and $t = 273$, and admitting that the preliminary compression triples the pressure, there arises for the three cases $\rho = 0{\cdot}11 = 0{\cdot}32 = 0{\cdot}27$. As T is greater always than here assumed, these values are minima.

The efficiency of atmospheric motors would be equal to unity if

the expansion were carried to infinity, but the work would become nothing. The maximum work is obtained when $t' = t$; then $t'' = \frac{t^2}{T}$; this case can only be realised with a regenerator, for it is necessary to give up cooling the gas to a temperature t'' less than the exterior temperature.

E. F. B.

Sand-wheel Motor.

(American Machinist, Sept. 8, 1883.)

In Virginia (Nevada) there is a large overshot wheel operated by sand instead of water. It is located in a sandy plain, and it was at first proposed to drive the machinery by wind; but while, on the whole, this was sufficient for the purpose, it was too unsteady in action; so the wheel was constructed and the windmill used by means of an endless bucket-belt to elevate the sand to a reservoir, from which the flow is controlled, and passing to the wheel gives a regular speed in spite of the fluctuations of the wind power.

The Sewerage and Refuse-Disposal of Towns.

By Prof. Virchow.

(Vierteljahrsschrift für öffentliche Gesundheitspflege, vol. xv., 1883, p. 39.)

At the tenth meeting of the German Health Society, the following six theses were submitted by Professor Virchow, of Berlin, with a view to their discussion, but not for formal adoption.

1. Water-cleansing and waterseals are essentially needed for soil-pipes in houses.

2. Long-continued storage of fecal matters, either in middens or cesspools, in boxes or in tubs, must be avoided.

3. Choice may be made, in accordance with local circumstances, either of the direct removal of the excreta from dwellings in tubs, or of their discharge into closed channels or drains.

4. The introduction of sewage into public watercourses is in all cases objectionable. In towns having upwards of 100,000 inhabitants, this practice should in no case be permitted. In towns under 100,000 it should only take place where the conditions of current-velocity are especially favourable, and then only when proper precautions are adopted for disinfection and defecation.

5. The introduction, also, into public watercourses of street- and house-drainage water, in the case of large and moderate-sized towns, should only be permitted after thorough deposition of the sediment, which process may require to be further aided by chemical treatment, in accordance with the quantity and quality of the water which has to be dealt with.

6. The agricultural employment of fecal matters must be subject to strict sanitary supervision; but no more should be expected

from sewage grounds, in the vicinity of towns, than what has been insisted upon in the case of ordinary agricultural operations of a like nature.

In dealing with the first proposition, Professor Virchow stated that even Captain Liernur, who had been foremost in asserting the sufficiency in his closets of a seal consisting of urine, had recently abandoned this position, and had admitted the advisability of the use of water. With respect to the second proposition, he pointed out the impossibility of ensuring the necessary sanitary conditions when any system, hitherto introduced, of storing excrement in the vicinity of dwellings was resorted to. Even in the case of tubs the intervals of removal were frequently so lengthy that dangerous decomposition might arise.

The three following theses are intimately connected, and Dr. Virchow alluded to the difficulty of removing polluting ingredients from water, and stated that he was greatly opposed to the discharge of fecal matters into streams. The self-cleansing powers of rivers, upon which so much reliance has been placed, have, he believes, been much exaggerated. Experiments at the Berlin sewage-farm have proved how rapidly a certain degree of improvement in polluted water may be attained, but they have also demonstrated how long and how far the evil effects of river-pollution may continue. He observed a growing tendency on the part of towns to resist the cost involved in dealing with polluted water; but, to prove its necessity, he stated that towns situated on the sea coast, where the speedy discharge of sewage into the sea would be considered the most ready way out of the difficulty of dealing with this question, were gradually calling for some better plan of disposing of their sewage. He noticed the difficulty of persuading agriculturists of the value of sewage water, and insisted on the need of providing sewage-grounds independent of the surrounding farmers, who will only take the sewage water when it suits their purpose, and who frequently reject it when the town is most desirous of sending it to them.

With respect to his final proposition, he showed that often enough no difficulty is made when farmers apply excrementitious matters to their land, and which, when washed into streams and rivers by heavy rainfall, may give rise to wholesale pollution, whilst the least discharge of sewage into streams by towns is made the occasion of widespread complaint.

G. R. R.

Sewage-Disinfection. By Dr. Emmerich.

(Vierteljahrsschrift für öffentliche Gesundheitspflege, vol. xv., 1883, p. 62.)

Speaking on the fourth thesis of Professor Virchow, with respect to the requisite disinfection of the excreta, Dr. Emmerich pointed out the difficulty and expense of carrying this out effectually. By disinfection is meant the destruction of the germs. The use of

heat is in this case manifestly impossible, and the only means available is the employment of such chemical substances as carbolic acid, chloride of zinc, sulphate of copper, quicklime, &c. If the first of these disinfectants be used, it is necessary, according to Koch's experiments, to introduce the excreta into a 5 per cent. solution of the acid, and to allow the mixture to stand for two days. The excreta produced daily by a population of say 100,000 persons, amounts to 138,590 kilograms (136·3 tons), to deal with which 6,929 kilograms (15,272 lbs.) of carbolic acid would be required, costing at least 6,929 marks (£346 9*s.*) per diem, or 2,529,085 marks (£126,454) per annum. This would need a sewage-rate of not less than 30*s.* per head. The most favourable results would be obtained by the use of corrosive sublimate, as a 1 per cent. solution only would be necessary, or a total of 1,385 kilograms (3,054 lbs.) daily; the value of which would be 9,310 marks (£465 10*s.*) for the above population. But it would be unwise to place so dangerous a substance in the hands of every householder, and the disinfected sewage would poison the watercourses over a large area. In fact, Koch's experiments have proved that no means are extant by which it would be possible effectually to disinfect the excreta, except at a cost which would be prohibitive.

Passing on to other modes of treatment, Dr. Emmerich states that rapidly-flowing water furnishes the best method of disinfection, as Koch has proved that while the germs of anthrax were only destroyed in three hours when exposed to a temperature of 140° Cent., they were killed in two minutes in hot water. This amazingly rapid action being due, he considers, to the chemical or physical influence of water, as, for instance, by rupturing the membrane of the spore, or in a manner still to be ascertained.

By means of his own researches the Author had found that blood taken from a sheep infected with anthrax, and used in fractions of a drop for the innoculation of rabbits, produced fatal results in less than twelve hours. Whereas 1 cubic centimetre of this same blood, violently agitated with 200 times its weight of Isar water for two hours, and used in quantities of 25 cubic centimetres for sub-cutaneous injection into rabbits, was wholly without evil effects, although, as seen in the microscope, the fluid contained thousands of the anthrax bacilli, and the volume used for injection in the latter case conveyed at least ten drops of the infected blood. He believed that he had been able to prove that the specific poison of anthrax lost its power by agitation in the presence of water. In the same way he had shown that sewage-water, which, when used without dilution, produced fatal results upon rabbits in from twelve to thirty-six hours, lost its evil effects if agitated for several hours with an equal volume of river water. He considered, therefore, that he had established the extremely important facts that the movements of the air and the movements of water are the great purifying processes of nature, and that the cleansing powers of rivers are due to their rapid motion.

G. R. R.

The Employment of Coal-Gas.

(Gesundheits-Ingenieur, June 30th, 1883, p. 337.)

The great attention devoted to the introduction of electric lighting has rather turned the thoughts of inventors from recent applications of coal-gas to the production of power; and though Sir William Siemens, during the scare occasioned by the new illuminant, pointed out that gas companies might in the future reap large advantages from the employment of gas for the purpose of heating and cooking, comparatively little notice has been given to the Otto gas-engine, which is so heartily despised by all those who are interested in steam-engines and boilers. This motor is destined, when used in conjunction with privately-owned gasworks, to supersede the steam-engine, and will undoubtedly become the chief source of power in the future.

To prove that gas-engines worked by means of gas supplied from special works are cheaper than steam-engines two examples are given. The silver-plate factory of Messrs. Wilkens and Sons, at Hemelingen, near Bremen, had a 30-HP. steam-engine, for which was substituted a 50-HP. gas-motor, supplied from the Deutz Works; the gas employed being from their own gasworks, which had been carried on by them for some years. The gas costs, upon an annual consumption of 150,000 cubic metres (5,297,000 cubic feet), including every expense of interest, sinking fund, wages, &c., and with coal at the high price of 140 marks per 10,000 kilograms (14·23*s.* per ton), only $3\frac{1}{10}$ pfennige per cubic metre (10·5*d.* per 1,000 cubic feet). The 50-HP. gas-motor uses $\frac{7}{10}$ of a cubic metre per HP. per hour (24·7 cubic feet), at an hourly cost of $2\frac{17}{100}$ pfennige per HP. (0·26*d.*); whereas a 50-HP. steam-engine would cost at the least 3·88 pfennige per HP. per hour (0·46*d.*), or nearly double the amount of the gas-engine.

The following figures may serve still further to elucidate the relative expense of gas- and steam-motors, stated with reference to their respective use of coal. A 50-HP. gas-engine with twelve hours' daily use, during twenty-six days per month for twelve months, at the rate of $\frac{7}{10}$ of a cubic metre per HP. per hour, employs 131,040 cubic metres of gas (4,627,000 cubic feet).

		Marks.
To produce these 131,040 cubic metres of gas there will be needed 436,800 kilos. of coal at 140 marks per 10,000 kilos. . .	..	= 6,115·20

From this must be deducted the receipts for residuals as follows:—

174,720 kilos. of coke at 200 marks per 10,000 kilos.	=3,494·40	
Tar equal to 40 kilos. of tar per 1,000 kilos. of coal = 17,472 kilos. of tar at 6 marks per 100 kilos.	=1,048·32	
Ammonia-liquor, say	200·00	
		4,742·72
Total outlay for coals		1,372·48

The engine runs 12 hours × 26 days × 12 months = 3,744 hours.

The cost of the gas, therefore, stated in value of coal, is $\frac{1,372 \cdot 48}{3,744}$ $= 36 \cdot 66$ pfennige per 50-HP. per hour, or $\frac{36 \cdot 66}{50} = 0 \cdot 73$ pfennig per HP. per hour. Stated in weight of coal, taking 100 kilograms at 1·40 mark, the result is 1·03 kilogram (2·26 lbs.). A well-constructed 50-HP. steam-engine would, however, require, according to official figures from 2 to 2½ kilograms (4·409 to 5·51 lbs.) per HP. per hour; and most steam-engines need 5 to 6 kilograms of coal.

The following figures, obtained from the sugar-works at Elsdorf, prove that in the case of gas-motors, where the consumption is on a larger scale, there is even a larger relative economy as compared with steam. This factory has three motors, one of 60 HP. and two of 20 HP. each. The former works continuously, the latter at intervals only. The duty may, for the purpose of this calculation, be taken at an average of 70 HP. The gas used during one year was—

For gas-engines . . .	256,904	cubic	metres.	
„ illuminating purposes	165,270	„	„	
Total . . .	422,174	„	„	=(14,909,000 cubic feet).

The net cost of coal used for gas in the case of the motors was 1,290 marks. The gas used per HP. per hour was 0·666 cubic metre (23·544 cubic feet); the expenditure on coal to produce which was 0·327 pfennig, or, in weight (taking 100 kilograms of coal at 1 mark, a common price in the Rhine district), 0·327 kilogram (0·72 lb.) per HP. per hour.

The price of the gas made at the Elsdorf factory, including interest on capital, sinking fund, and wages, is 3·02 pfennige per cubic metre (10·26*d.* per 1,000 feet) on the above total production of 422,174 cubic metres; whilst that made at Hemelingen, on a far smaller volume of gas, was only 3·10 pfennige. The reason of this relatively low cost at the latter factory lies no doubt in the fact that the works at Hemelingen were built on the plan of Francke, which involves a much cheaper apparatus, in which the generator retorts are set on a patent system without hearths. To the question of smoke prevention the gas-motor affords a perfect solution, and gas-works may be regarded as the future source of power.

G. R. R.

Working up Ammoniacal Liquor. By Dr. Kunath.

(Journal für Gasbeleuchtung, 1883, p. 323.)

Having decided to work up the ammoniacal liquor at the Gas-works, the Author erected a distilling apparatus on Dr. Gruneberg's system, together with the other vessels necessary for making

sulphate of ammonia. The whole plant, including the shed in which it was placed, cost 8,000 marks (£400), and the first year's working gave the following results:—

	Marks.
Receipts.	
1,150·17 cwt. of salt at 19·40 marks . . .	22,315·82
Expenditure.	
Interest on 8,000 marks at 5 per cent. . . .	400·00
Amortisation	400·00
1,194·97 cwt. of acid (at 50° and 60° Baumé)	5,468·63
220 cwt. of lime	427·00
Coke and breeze	213·90
Wages, packing, and repairs	1,181·34
Total	8,090·87
Receipts	22,315·82
Expenditure	8,090·87
Profit	14,224·95

The expenses amounted to 7·03 marks per cwt. of sulphate, and the salt produced, per 100 kilograms of coal carbonized, was 0·624 kilogram.[1]

The Author is of opinion that the use of the above apparatus would prove remunerative in gasworks carbonizing 1,000 tons of coal a year and upwards.

G. E. S.

Testing Gas-Liquor for Ammonia. By Dr. Knublauch.

(Journal für Gasbeleuchtung, 1883, p. 317.)

The usual method of testing ammoniacal liquor at gasworks is with the hydrometer, *i.e.* according to its specific gravity, it being assumed that the percentage of ammonia increases with the specific gravity. This assumption is altogether erroneous. Gas-liquor contains ammonia principally in combination with CO^2 and H^2S. As these salts exist in very different proportions in the liquor, and their solutions possess different specific gravities, the specific gravity of the liquor cannot be proportional to the quantity of ammonia it contains. Carbonic acid and hydrogen sulphide are formed in very different proportions in coal-gas. It has been proved by experiment that even out of different samples of Westphalia coal the proportion of H^2S varied from 1 to 4, and also that the quantity of sulphur contained in the coal bore no relationship to the sulphuretted hydrogen formed in the distillation of the

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[1] This is equal to about 14 lbs. per ton, or little more than half the usual production in English gasworks.—G. E. S.

coal. Besides this, it depends upon the manner and degree of the purification by washing how much of both acids become fixed by the liquor. Even when the same coals are carbonized at the same works, the liquor produced may vary considerably. Gas-liquor at the Cologne Gasworks of the strength of 1° Baumé was found by the Author to contain on the average 0·724 per cent. of ammonia. A sample of liquor of 2°·31 Baumé contained 1·958 per cent. of ammonia, according to exact analysis, but according to the specific gravity it would apparently contain $0 \cdot 724 \times 2 \cdot 31 = 1 \cdot 672$ per cent., so that the specific-gravity test would give 14½ per cent. too little ammonia.

To enable the experimenter to determine in a simple and rapid manner the exact percentage of ammonia contained in gas-liquor, the Author has devised the following method. 100 cubic centimetres of gas-liquor are placed in a ½-litre flask, and filled up to the mark with distilled or rain water, making a total of 500 cubic centimetres. A small flask, fitted with a glass stopper, is then filled two-thirds full with the diluted liquor, and a few pieces of burnt lime thrown in (about ·5 grams to 100 centimetres), and the flask allowed to stand for an hour with frequent shakings. 50 cubic centimetres are then titrated with a standard acid solution, a few drops of Rosalic acid solution being added to mark the point of neutralization. The acid is added from a burette or alkalimeter, which is graduated to show the percentage of ammonia equivalent to the quantity of acid used to neutralize the liquor.

The following tests made with this method correspond very nearly with the results obtained by distillation:—

Distillation.	Lime Method.
1·795	1·75
1·901	1·97
1·958	1·81
2·006	1·95
2·332	2·37

G. E. S.

Prevention of thick Tar in the Hydraulic Main. By Dr. Kunath.

(Journal für Gasbeleuchtung, 1883, p. 321.)

The Author, who is the Manager of the Dantzic Gasworks, having been troubled with the usual stoppages in the ascension pipes and hydraulic main of gas-retorts, especially when using English coals, tried dissolving the thick tar with various substances, such as hot water, petroleum, linseed oil, and turpentine. Water and petroleum had no effect, other than that of making the tar still harder. Linseed oil dissolved the tar slowly to some extent, but turpentine dissolved it so quickly and completely that in a short time only the small pieces of coal and dust remained at the bottom of the solution.

To prevent further stoppages occurring, a hole was bored in the end of the hydraulic main, large enough to admit the socket of a ½-inch pipe, and through this a pipe was inserted, along the bottom of the hydraulic, by which turpentine could be introduced. A 9-inch bend was also fixed on the end of the hydraulic, and a square box at the side, by which the thick tar could be raked out.

G. E. S.

Experiments with the Schultz-Roeber Mechanical Stoker.

By Walther Meunier.

(Bulletin de la Société Industrielle de Mulhouse, 1883, p. 25.)

The Schultz-Roeber mechanical stoker has been applied to one of the boilers at the works of Messrs. Schlumberger and Co., by whom it has been modified and improved in its details. There is a feeding hopper at the front, from which the fuel is delivered over a dead plate, upon an inclined grate, whence it falls, in the condition of coke, into a rectangular fireplace of firebrick, having a horizontal grate at the bottom. The inclined grate is provided with an air-tight ashpit, and all the air from combustion is admitted below the horizontal grate, partly through an opening at each side, and partly through the front, which is open, and controlled by a damper. Air for the combustion of the gases passes upward through the body of coke, and, being heated, combines readily with and burns the gases. The bridge is carried up, and is inclined forwards, towards the front, and so facilitates the intermixture of the elements and promotes combustion.

Comparative experiments were made with the furnace in its original condition in March 1882; and in October 1882, after having been at work for several weeks on the Schultz-Roeber system. In both cases the gaseous products were submitted to analysis.

The boiler with which the experiments were made was of the ordinary French type, having the body 45 inches in diameter, and 19 feet 8 inches in length, and three heaters 19⅝ inches in diameter, and 23 feet 7½ inches long. The heating surface was 365 square feet, and the area of the fire-grate, before the alteration, 19½ square feet. The ratio of the fire-grate to the heating surface was as 1 to 18·6. A Green's economizer of ninety-six tubes was appended. After the adaptation of the Schultz-Roeber system, the proportions were:—Area of the inclined grate, 13·58 square feet; of the horizontal grate, 5·91 square feet; together, 19·50 square feet, the same as before the alteration. The inclination of the principal grate was 1 in 3·60. The heating surface was reduced to 353 square feet, in consequence of a firebrick arch built over the dead-plate.

Two trials on two consecutive days were made of the ordinary furnace and the Schultz-Roeber furnace, as described. The coal

used was Kœnig III. The following are the principal results of the trials, averaged for each furnace:—

	Ordinary Furnace.	Schultz-Roeber Furnace.
Duration of the trials	11h. 30m.	11h. 30m.
Sensible pressure in the boiler per square inch	84·5 lbs.	74 lbs.
Coal consumed per hour per square foot of grate	14 „	15·4 lbs.
Temperature of feed-water	48°·5 F.	59° F.
Water as at 32° F. evaporated per lb. of coal	5·44 lbs.	6·38 lbs.
Temperature of the feed-water on leaving the economizer	228°·5 F.	205°·0 F.
Gain of temperature	180°	146°
Temperature of the gaseous products on leaving the economizer	317°·5 F.	207°·5 F.
Temperature of the atmosphere	76° F.	67°·5 F.
Humidity of the coal, percentage of water in parts of dry coal	9·2 per cent.	4 per cent.
Ash and clinker, per cent.	19·4 „	24·4 „

The evaporation reckoned for dry coal was at the rate of 5·94 lbs. of water per lb. of coal in the first series of trials, and 6·63 lbs. in the second series.

From the results of analyses of the gaseous products of combustion, it appears that, whilst there was found from 0·84 per cent. to 1·22 per cent. of carbonic oxide for the ordinary furnace, there was none at all for the Schultz-Roeber furnace.

D. K. C.

Statistics of Public Lighting in Paris.

(Annales Industrielles, 26 August, 1883, p. 257.)

The lighting of the public thoroughfares of Paris at present requires 43,089 gas-burners, and 429 wicks for petroleum or colza-oil. The various municipal establishments use 25,000 gas-jets. In 1883, the cost of lighting the public ways will amount to 5,473,000f. (£218,920), and that of lighting the municipal buildings to 1,200,000f. (£48,000). If allowance be made for 600,000f. (£24,000) to be reimbursed by various persons for cost of lighting effected on their behalf, the total charge to the city for 1883, will be about 6½ millions of francs (£260,000). A gas-burner consuming 5 cubic feet per hour, costs yearly, maintenance included, 104f. 77c. (£4 3*s.* 10*d.*) for an average night of ten hours. For each oil-lamp, the cost is, for colza-oil, 172f. 34c., for petroleum, 159f. 72c. A staff of 76 persons superintends the lighting, public and private. Every evening the gas is tested at eleven laboratories stationed in different parts of the town, so that the quality of the make of the gas-company's different works may not go uncertified. A large central laboratory in the Quai de Béthune is occupied with photometrical tests of processes invented to improve the manufacture of gas, or to substitute new illuminants therefor.

F. G. D.

The Gas-Supply of the German Empire. By F. Eitner.

(Journal für Gasbeleuchtung, June 1883, p. 435.)

This is a Paper read before a meeting of the German Association of Gas and Water Engineers at Berlin, descriptive of the extent and development of gas-lighting and supply in Germany.

The Author finds, by reference to the reports of the Imperial Statistical Office, that the German empire contains 2,528 townships and villages of more than 2,000 inhabitants each, and that these places have a total population of 16,657,000. Of these 2,528 places, 608 are supplied with gas from altogether 610 gas-works. In addition to these 610 works for the supply of the general public, there are between 300 and 400 private gas-works for the supply of factories, railway stations, &c. Some of these latter are very important works, as, for instance, the gas-works at Messrs. Krupp's steel-works at Essen, where the yearly make of gas amounts to over 300,000,000 cubic feet.

At the 610 public gas-works, 1,488,800 tons of coal are annually carbonized, and the yearly make of gas is 15,324,000,000 cubic feet. As there are 51,000,000 tons of coal raised annually from German coal-pits, it follows that, provided all the coal used for gas-making were obtained from inland sources, the proportion devoted to gas-making would be 2·9 per cent. of the total production.

In comparing the gas production of Germany with that of other countries, it is seen that, as regards England, the consumption of gas in London alone exceeds the total of all Germany by about 6,000,000,000 cubic feet per annum. Paris consumes rather less than two-thirds of the whole of Germany, while Berlin absorbs 21·6 per cent. of the total German consumption.

The consumption of gas per head of population per annum reaches in London 5,500 cubic feet, in Paris 4,000 cubic feet, and in Brussels 3,000 cubic feet, while in Berlin it amounts to 2,800 cubic feet. In the other German towns it varies from 1,000 to 350 cubic feet per head, according to the size and position of the place. There are even places where it only amounts to half the latter figure. In general the consumption of gas is greater, and its use more prevalent, in the western towns, and diminishes towards the eastern portion of the empire.

Of the 610 works before mentioned, 290, or 47½ per cent., are the property of the municipalities, while 320, or 52½ per cent., are in the hands of companies or individual proprietors. The municipal gas-works carbonize 65 per cent. of the coal used, and the companies 35 per cent. Of the total quantity of gas delivered, 14 per cent. is devoted to the lighting of streets and public buildings. There are 174,280 street lamps. The hourly consumption of gas in each lamp varies from 120 to 250 litres (4½ to 9 feet); in one town it is as much as 400 litres (14 cubic feet). The average, however, is 157½ litres, or 5½ cubic feet, per hour.

The length of streets lighted is 8,550 kilometres (= 5,300 miles), and the average distance of the lamps apart from one another is 43 metres, or 53·4 yards.

The gas consumed by private consumers is 77 per cent. of the total quantity delivered, leaving 9 per cent. as the loss by leakage.

The total number of consumers is 343,376, and the number of burners, so far as can be ascertained, 4,275,000.

The capital expenditure on the municipal gas-works averages 509,787 marks per 1,000,000 cubic metres (£728 per 1,000,000 cubic feet), and that of the works which are in the hands of companies averages 501,854 marks per 1,000,000 cubic metres (£716 per 1,000,000 cubic feet).

Of gas-motors, there are 3,250 in use in the empire, having a total nominal 6,760 HP. The Author, however, estimates the actual power developed at 1,000,000 HP.,[1] and calculates that the power exerted by the gas-engines in use amounts to 7 per cent. of the total motive power obtained by the use of steam-engines in the country.

The Author concludes his Paper by stating that the stationary engines of Germany consume in round numbers 9,900 kilograms of coal per annum, and that therefore the coal consumption of German gas-works only equals 15 per cent. of that used for steam purposes in the stationary engines of the empire.

G. E. S.

Comparison of Gas and Electricity as to Lighting- and Heating-Powers. By Georges Guerolt.

(La Lumière Électrique, vol. ix., 1883, pp. 271–274.)

The Author seeks to exactly determine (1) the quantity of heat disengaged by a Bengel gas-burner giving 1·73 carcel, and consuming 140 litres of gas an hour; (2) the quantity of heat which in this burner is used in furnishing light, and, by difference, that constituting the heating power exclusively; (3) the quantity of heat necessary to produce the same luminous effect in an electric incandescence-lamp, and in an arc-light. The incandescence-lamp was of the Edison type A 3. The Bengel burner is shown to develop in an hour 1,126 calories of heat, equivalent to 1·73 HP. An Edison lamp of type A 3 gives 1·73 carcel light with an electromotive force of 100 volts and 0·75 ampère current. The heat-value per hour is therefore 64·8 calories. The weight of the carbonized fibre is about 15 milligrams, which very nearly corresponds, the Author points out, to the amount of pure carbon passing from the gas into the gas flame in a second. Whence it is deduced that 1,035 calories are waste heat in the gas flame; or, for the same

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[1] *Sic* in original.

lighting power, gas uses seventeen times more heat than the electric lamp.

The Cance arc-lamp was employed, with an electromotive force at the terminals of 44 volts and 7·5 ampères of current, corresponding to 0·074 calorie per second, and gave about 160 carcels light, or nearly nine times the light with four times the quantity of heat as in the incandescent lamp.

P. H.

Behaviour of Mineral Wool around Steam-pipes.

By F. R. Hutton.

(Transactions of the American Society of Mechanical Engineers, 1882.)

A 5-inch steam-pipe, containing steam of 40 lbs. pressure per square inch, was coated with mineral wool, or slag-wool, inclosed in a casing of galvanized iron. On uncovering the pipe, it was found to have suffered rapid corrosion, and could be removed in flakes. It was observed that where the wool was entirely dry, the pipes were in as good condition as when new; but where moisture was present, and had permeated the wool, the surface of the pipe was corroded.

In general composition, slag-wool is a compound of silica with bases, usually lime, magnesia, and other matters. The element sulphur is not at all unusual in slags. It may be present combined in a sulphide, or in a hyposulphite, probably with lime as a base. In either case, by moisture and heat, sulphur would be released as an oxidizing agent, which would be only too likely to fasten on the iron. The presence of sulphur in solutions of scale taken from the pipe has been unmistakably proved; and this appears to show that corrosion must have been more active than that due to an innocuous conductor.

Professor Egleston, in discussion on the Paper, insisted that wherever blast-furnace wool is to be employed, absolute freedom from moisture must be ensured. So long as the wool is kept dry, and not allowed to "pack," there is probably, he says, no other substance that is as good for the purpose; but if it become packed it loses its non-conductive power; if it become moist, it sags together, becomes packed, and is worthless; and if the moisture is at all constant, there will, he concludes, be a decomposition of the slag, and an attack on the iron by sulphuric acid set free, or by organic acids if the material comes from the drainage of the soil.

D. K. C.

Modern Smoke-Preventing Furnaces for Boilers. By C. Bach.

(Zeitschrift des Vereines deutscher Ingenieure, vol. xxvii., 1883, p. 177.)

In this Paper the Author describes various smoke-preventing furnaces, more especially those in use in the city of Basel, where 60 per cent. of the steam-boilers are provided with them. The furnaces which have given the best results are the Ten-Brink type, of which thirty-one are in use in Basel, where they have been very successful.

The Author describes the various plans in use, and shows how the best possess, in a greater or less degree, the essential points of the Ten-Brink type, the chief features of which are the use of a steep grate down which the fresh fuel slides by gravity as it burns away below, and also the adoption of a projecting water-bridge, brick arch or other appliance, by means of which the products of combustion from the lower part of the grate are doubled back over the fresh fuel which they distil, when the mixed gases meet the air which enters at the top over the fuel and burn without smoke.

The Paper is illustrated with many diagrams of the apparatus described, and of several modifications of the Ten-Brink grate suitable either for stationary or locomotive boilers.

W. P.

Improvements in Locomotives.

Notes from the Master Mechanics' Convention.

(American Machinist, vol. vi., 1883, p. 5.)

The first Paper read was on "Improvements in Locomotives, with reference to Efficiency and Style and Finish," by F. W. Dean. In opening his subject the Author criticised the style of American locomotives as regards appearance, and condemned the use of heavy mouldings on sand-boxes, dome-covers, and other parts. He also approved of the use of iron cabs instead of wood, as accidents from burning are thereby prevented.

The Author remarked that the American locomotive was a remarkably wasteful machine, both in the use of the fuel and in the use of the steam after it was generated. He considered that the fuel in American engines was consumed too rapidly, and advocated larger grate area; he approved of the recent practice of extending the smoke-box so as to catch sparks, but thought that sparks should be arrested in the fire-box by a brick arch or otherwise.

The frame of the American locomotives Mr. Dean considered took up too much room, and lacked vertical stiffness, and he recommends the adoption of the British slab-frame as an improvement.

The Author also advocated taking the steam through a perforated pipe, in preference to a steam dome, as the steam is thereby procured drier, and the boiler is less likely to prime, while domes are a source of weakness and expense. The Author remarked that the ordinary coupling-rods, cross-heads, and guides are not what they should be. Coupling-rods with bushed eyes are simple, cannot be tampered with, and have been known to last for three years without renewal; the Author proposes to use steel tubes for coupling-rods, and cast-iron bored-out guides cast in a piece with the cylinder covers. Solid pistons were almost universal in England, and would be in America, if understood.

The Joy valve-gear the Author considered the best ever devised for a locomotive, and destined to supersede the link.

At the discussion, Secretary Setchel said that Mr. Dean was a young man without experience, and with ideas of English extraction, and that his opinions could not be endorsed without comment. Mr. Setchel doubted if the design of the American locomotive was to blame for its waste of fuel; the difference was due to the more careful firing of the English engine; another reason was that the American engine did more work. Mr. Setchel said that, in the experience of all Western men, the water deflector bridge was a failure, and had in most cases been taken out because it would burn and crack, and brick arches had been put in as a substitute; still he considered that to leave the brick arch, and take away the water-table, would be a retrogression. Mr. Setchel could not agree that a slab-frame was the best, but was willing to yield a point in order to get a wider fire-box, and slab-frames had been used with success on the Boston and Albany Railroad.

Mr. Smith, of the Philadelphia and Erie Railway, remarked that he got 10 per cent. economy by the brick arch.

Mr. Sedgley, of the Lake Shore Railroad, said that their recorded tests showed that the brick arches made no saving, so they pulled them out.

Mr. Flynn, of the Western and Atlantic Railroad, had tried the brick arch and abandoned it.

Mr. Smith explained that his first experiences were similar to those of Mr. Flynn and Mr. Sedgley, but he found at the front of the arch a bank of sparks; he concluded that these should be got rid of, and experimented with the petticoat pipe until he got the draught to keep the arch clear, after which he found an economy of fuel.

W. P.

Mehlis and Behrens' Valve-Gear.

(Der Civilingenieur, vol. xxvi., 1883, p. 618.)

The engine described in this Paper is furnished with double-beat valves, which are driven by Mehlis and Behrens' valve-gear. The gear belongs to that class in which the closing, as well as the

opening of the valves, is directly controlled by the engine. The gear cannot well be fully described without reproducing the drawings, but it consists generally of a horizontal shaft placed parallel to the cylinder, on which shaft are keyed two eccentrics; on each eccentric strap is a lug which slides on a round rod; the lower end of the rod is guided in an arc by a vibrating link; on the upper part of the rod above the eccentric a block slides, which is connected by a rod and bell-crank to the admission-valve. Every point on the first-mentioned rod describes a pear-shaped curve, and as the sliding block is shifted up and down by the governor, the motion of the valve and the admission of steam are varied. The exhaust-valves are driven directly from other points of the eccentric-straps. It is claimed for this gear that it is simple and has few moving parts, and gives a satisfactory distribution of steam.

The engine, which is fully illustrated, was built to supply the motive-power for the electric lighting at the Berlin Hygiene Exhibition.

W. P.

Note on the Milling Plant and Process of Messrs. Marriotte, Brothers, and Boffy. By D. A. Casalonga.

(Mémoires de la Société des Ingénieurs civils, 1883, p. 222.)

This is a Paper read before the above Society on the milling-plant designed and introduced by Messrs. Marriotte, Brothers, and Boffy. The Author calls attention to the pressure of foreign competition which is being keenly felt by French millers, more particularly since the introduction of the Hungarian plant and processes, and he referred to the Paper by Mr. Kremer on this subject.[1]

Messrs. Marriotte, Brothers, and Boffy have endeavoured to find a system which should be superior to the Hungarian roller-mills, and, after a great deal of experimenting, have perfected the plant described in the present Paper.

The essential part of their apparatus is a special mill, constructed with a pair of metallic disks instead of stones; the grinding faces of these disks are channelled in a peculiar manner illustrated in the Paper, and it is this "dress" which constitutes an important element in the system. The mills are used in a somewhat similar manner to the successive pairs of stones in an ordinary high-milling plant.

The Author states that the machines and systems described in the Paper have great advantages over stones; the first cost is less, as fifteen metal mills replace twenty pairs of stones; they take less power and give a better yield, and do away with the labour of dressing. The Author also considers that the metal-disk mills are

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[1] Minutes of Proceedings Inst. C.E., vol. lxvi., p. 426.

superior to roller-mills, and that they deal with the grain in a more rational manner.

The Author describes one form of the mill in which the "dress" is so arranged that by altering the distance between the disks, one mill and a single purifier can be made to perform the whole series of operations by successive passes through the same machine; this enables a portable plant to be constructed that is of great use in agricultural districts.

The Author gives the following as a sample of the results obtained with the apparatus described in the Paper, using wheat (French?) of the year 1882:—

40 per cent. semolina, equal to the best Hungarian qualities.
20 to 22 per cent. first flours, equal to good brands.
4 per cent. seconds flours.
(Making a total of 64 to 66 per cent. of excellent white flour.)
4 per cent. grey flour.
2 to 3 per cent. thirds and fourths.

W. P.

On the Application of Electricity to Subterranean Ventilation.

By B. R. Förster.

(Jährbuch für das Berg- und Huttenwesen in Sachsen, 1883, p. 30.)

In a memoir upon the separate ventilation of colliery workings, published in 1882,[1] mention was made of a method of driving a ventilator underground by an electric current transmitted from the surface, as then being in course of execution. The arrangements were completed in the autumn of 1882, and the present communication contains the results obtained subsequently in regular work. The apparatus, which has been executed by Messrs. Siemens and Halske, consists of a small steam-engine at the surface, driving a primary dynamo, the current generated being transmitted by a copper wire to the secondary dynamo, which is coupled to the ventilator underground.

The steam-engine is of the rotatory piston kind (Dolgoruki's system), and of the following dimensions:—

Height of cylinder and piston	123 millimetres,	4·84 inches.
Inside radius	40 „	1·57 „
Outside „	80 „	3·15 „
Revolutions per minute		800

The available work measured by a friction brake is 2·56 HP. This engine is somewhat larger than is actually required for the work, as, according to Siemens and Halske, one of the same size in their works, working at $5\frac{1}{4}$ atmospheres boiler-, or $4\frac{1}{2}$ atmospheres

[1] Minutes of Proceedings Inst. C.E., vol. lxx., p. 496.

piston-pressure, realized 9·36 HP. In the present instance the effective boiler-pressure is only 3½ atmospheres.

The actual steam-consumption cannot be very accurately determined, owing to the difficulty of taking indicator-diagrams upon engines of this class. Assuming, however, that a well-constructed engine of such small power should realize 50 per cent., the gross HP. for the above duty will be 5·12 HP. The dynamos are of the well-known Siemens construction, and both are of the same size, No. D 8 of the makers' list. The armature of the primary machine is attached to the crank-shaft of the steam-engine, and revolves at the same speed (eight hundred revolutions per minute). The conductor joining the two machines is carried 112 metres (367 feet) above ground, 261 metres down the shaft, and then 407 metres through the workings. It consists of a copper wire, 7·25 millimetres (0·28 inch) diameter, carefully supported upon stoneware insulators, placed at intervals in the shaft and levels. The conductor for the return current is formed by an old steel wire pit-rope, of 30 millimetres (1·18 inch) diameter, for a distance of 377 metres, while for the remaining distance a copper wire similar to the main conductor is used. The wire-rope was originally laid along the ground, where, however, it soon became very rusty from the damp, so that it has since been suspended from hooks driven at intervals into the roofs and sides of the level.

The secondary dynamo drives the ventilator by a strap, the shaft of the former making one hundred and twenty-four revolutions to one hundred of the latter. The ventilator is a simple centrifugal fan, by G. Schiele and Co., size No. 8, 1 metre in diameter, with a discharge-pipe of 0·196 square metre surface. The delivery, at five hundred revolutions, is stated to be 180 cubic metres of air at 20 millimetres pressure, requiring 1·66 HP. to drive it.

The fan is placed in the sixth main level, north from the Carola Pit, and is arranged to supply air through pipes of 300 millimetres (1 foot) diameter to four workings lying in different directions.

The first measurements were taken before the erection of the underground works, both engines and the fan being at the surface, and connected by 50 metres of copper wire. The fan discharged directly into the air, with a difference of pressure of at most 1 millimetre. Under these conditions, the results obtained were—

Experiment No.	Revolutions per Minute—			Air Exhausted per Minute. Cubic metres. (35·316 c. ft.)	Air Exhausted per Revolution of Fan. Cubic metre.
	Of Engine and Primary Machine.	Of Secondary Machine.	Of Fan.		
1	800	481	388	213·4	0·55
2	490	285	230	127·0	0·55
3	408	232	187	95·6	0·51
4	265	107	86	36·4	0·42
5	163	..	..	..	..

The volume of air in experiment No. 1 could not be measured, as the current was too strong for the anemometer; it has therefore,

been computed from that obtained in experiment No. 2, the amount being assumed to be proportional to the number of revolutions. When the steam-engine was slowed down to the speed of No. 5, no rotation of the armature of the secondary machine or of the fan could be obtained.

As previously stated, the available power of the engine, measured by the friction-brake when making eight hundred revolutions per minute, was 2·56 HP.; that of the secondary dynamo-machine, similarly measured when at the surface, with a circuit of only 50 metres, was 1·4 HP., corresponding to a useful effect of 54·3 per cent. The resistances of the current, and losses by friction of the rotatory part, and in the conversion of electric into mechanical energy for these conditions, are about 45·7 per cent. of the total energy of the motor.

When the distance between the primary and secondary machines was increased to 780 metres, the revolution of the latter for 800 of the former fell from four hundred and eighty-one to four hundred and forty-eight per minute; or the useful work diminished from 1·4 to 1·3 HP., or 3·9 per cent. of that of the motor. The Author does not, however, consider it certain that this difference is entirely due to increased resistance in the conductor, but that it is partly to be attributed to variations in steam-pressure and errors of observation in the course of the experiments. The ventilator underground makes three hundred and sixty-one revolutions per eight hundred of the surface-engines, at which speed the volume of air moved at 198 cubic metres per minute.

A certain amount of inconvenience was experienced from the noise made by the Dolgoruki engine, which led to its removal from the winding-engine house, where it was originally erected, to a special small house of its own. The noise was in no way attributable to the dynamo-electric machines. Another difficulty, which could not, however, be obviated, consisted in the currents induced in the telephone wires underground when both sets of conductors were carried along the same workings. It has therefore been found necessary to remove the telephone wires to a different part of the mine.

The cost of the whole arrangement was as follows:—

	£.	s.
1 Dolgoruki steam-engine	87	10
1 Dynamo-electric machine	67	10
Bed-plate for the preceding	5	0
1 Electro-dynamic engine	67	10
Packing and carriage	4	10
Erection of machines	4	15
1,183 metres copper wire	44	19
377 „ old steel wire rope	5	6
Fixing conductor	3	0
Total for steam-engine and electric transmission	290	0
1 Schiele's ventilator	36	10
Total	326	10

As regards the cost of working, the wear of the electric engines is very small, being principally confined to the brushes of the commutator, which probably will not exceed £5 yearly. Materials for lubrication and cleaning cost about £12 10*s.* yearly, or 11¼*d.* per day. No special engine-drivers are required, as the total daily work about them can be done in a quarter of an hour. The cost of steam, according to the conditions prevailing at the mine, is £9 6*s.* 9*d.* per HP. per annum, or, for 5·12 HP., £29 16*s.*, equal to 2*s.* 7½*d.* per day of twenty-four hours, or per 285·120 cubic metres of air delivered. Interest and depreciation on the cost of the plant amount to a further 2*s.* 8*d.* per day, making a total of 6*s.* 3*d.* per day, or per cubic metre 0·00015*d.* (about 3*d.* per 1,000,000 cubic feet).

The above figures, however, refer only to the theoretical quantity of air delivered at atmospheric pressure, while under the actual condition of work, with the fan blowing into several lines of pipe going in different directions, the delivery is very much smaller. Thus it was found that when blowing through five lines of pipes, with a total length of 200 metres, the total volume was only 31 cubic metres, which was further diminished to a total of 12·81 cubic metres when the length of pipes was increased to 567 metres. The cost per cubic metre would therefore be, in the first case, $\frac{198}{31} = 6 \cdot 4$ times, and in the second $\frac{198}{12 \cdot 8} = 14 \cdot 6$ times as much as that given above. The use of such very long lines of pipes must, however, be regarded as exceptional.

H. B.

Miners' Safety-Lamps. By Er. Mallard and Le Chatelier.

(Annales des Mines, vol. iii., 1883, pp. 35–68.)

The results obtained in the extensive series of practical experiments recently made by Mr. Marsaut[1] upon numerous varieties of miners' safety-lamps form the subject of considerable comment by Messrs. Mallard and Le Chatelier. One fact in particular, which his experiments have made known—namely that, when a lighted Mueseler lamp is slowly lifted into an inverted bell-glass containing an explosive mixture of air and lighting gas, the flame will sometimes pass out through the wire-gauze cylinder—has startled the confidence hitherto so generally felt in the practical safety of the Mueseler lamp. Having been already concerned in investigations for the French fire-damp commission, the Authors repeated for themselves Mr. Marsaut's experiments, at his invitation, and under different conditions; and they now give the conclusions to which they have been led.

The liability of the flame to pass out through the wire-gauze

[1] Minutes of Proceedings Inst. C.E., vol. lxxii., p. 248.

of any safety-lamp increases, they argue, firstly with the volume of the space enclosed within the gauze, secondly with the smallness of the outlet apertures through the gauze, and thirdly with the speed at which explosion can travel through the gaseous mixture encountered by the lamp. In the most explosive mixture of air and carburetted hydrogen, containing 12·2 volumes of gas to 100 of air, their experiments show that explosion travels at a speed of about 0·7 metre = 2·3 feet per second; while in the most explosive mixture of air and lighting gas, containing 21·2 volumes of gas to 100 of air, the speed is about 1·1 metre = 3·6 feet per second. Hence in experiments such as theirs, with explosive mixtures of lighting gas, the safety of wire-gauze undergoes a far severer test than it is ever exposed to in fire-damp. In these experiments moreover, the whole interior of the safety-lamp was entirely filled beforehand with the most highly explosive gas, and was then ignited by an electric spark; whereas in practice the fire-damp never fills more than the portion of the lamp above the flame of the wick, and is there more or less diluted by the products of combustion, which partially neutralize its explosive character.

When tilted about 40° from the vertical, the Mueseler lamp goes out at once in ordinary use. When so tilted however in an explosive current of lighting gas, the speed of the current being from 4 to 5 metres = 13 to 16 feet per second, and the top of the lamp pointing backwards in the contrary direction to the current, it does not go out, but almost invariably fires the outside gas. These conditions are so far removed from those likely to occur in practice, that the Mueseler lamp seemed safe from risk of firing the external gas, until Mr. Marsaut's experiments. In those trials it was generally by passing up through the horizontal annular diaphragm of wire-gauze on the top of the glass cylinder, and not up through the funnel or chimney, that in his opinion the flame fired the outside gas. But on stopping up the chimney with a plug, the Authors found the outside gas was never fired; the flame merely passed up through the diaphragm into the interior of the wire-gauze cylinder above, and stopped there, without further passing out through the gauze of the cylinder itself. Whereas conversely, when they stopped up the wire-gauze diaphragm by covering it with a ring of solid plate, and left the chimney open, the outside gas was fired in every trial; and above the chimney the wire-gauze cap of the cylinder showed distinct traces of the flame having passed out through it. The conclusion accordingly drawn by the Authors is that, so long as the freedom of passage through the diaphragm is sufficient for maintaining the proper flame, no explosion inside the Mueseler lamp, even in the most dangerous fire-damp, can fire the gas outside. The chimney however, in so far as it augments the speed with which the flame travels up through it, is regarded by them as a source of danger in a safety-lamp.

In regard to the Davy lamp, in which the sole protection lies in the wire-gauze cylinder enclosing the flame, the Authors have

invariably found that wire-gauze by itself forms but a precarious safeguard against explosion. They therefore look upon Davy lamps as untrustworthy for encountering fire-damp that is at all highly explosive; the use of these lamps in collieries ought to be absolutely forbidden, they consider, excepting for overmen specially cautioned to handle them with extreme care. Since lamps that go out in fire-damp are ill suited for exploring dangerous workings, on account of the explorer being thereby plunged into total darkness, the overmen are for this reason, even in Belgium, still allowed to use the Davy lamp, in spite of the serious dangers attending it. In any case, as appears from Mr. Marsaut's experiments, the wire-gauze cylinder should be made as small as possible, in accordance with the original recommendation of Davy himself. It would doubtless be advantageous too for the lamp to have both an inner and an outer cylinder of gauze.

Both from Mr. Marsaut's experiments and from their own, the Authors conclude that the dimensions of the Mueseler lamp can hardly be altered without introducing fresh danger. For further enhancing its safety, they suggest either raising the top of the wire-gauze cylinder a little higher above the top of the chimney, or covering the cylinder top with a solid cap, or else adding a second wire-gauze cylinder. But in exploring with the Mueseler lamp cavities filled with fire-damp in the roof of a colliery, the flame may readily make its way up into the interior of the wire-gauze cylinder; and continuing there, may fire the gas outside, if any disturbance occur such as that resulting simply from the lamp itself being hastily withdrawn. Either therefore the Mueseler lamp must not be used for such explorations; or else the fire-trier using it must keep the wick up to its full flame, instead of reducing it as ordinarily recommended. Although the blue tuft denoting the presence of fire-damp will then no longer be visible on the top of the full flame, yet the elongation of the flame itself will still serve as a sufficiently accurate indication; this mode of observation has already been long practised in the Bessèges collieries. A still safer plan would be to protect the lamp by shielding it with an outside screen or casing, as is done by Mr. Marsaut in his own lamp. Such a casing however is not free from disadvantage: the wire-gauze cylinder, no longer cooled by radiation, gets hotter; and after awhile the access of air to the flame gets impaired. If remaining long in gas that is nearly but not quite explosive, the wire-gauze cylinder might indeed get red-hot; while the casing would prevent the fact of its doing so from being noticed.

The improved Marsaut lamp, with two wire-gauze cylinders, one inside the other, and without chimney, can be tilted much further than the Mueseler before going out. It is indeed found by the Authors to be liable to the inconvenience of getting extinguished by a sudden downward movement, as when dropped from the hand to the ground. But they pronounce it in all respects the safest lamp that can be desired for encountering currents of

fire-damp; they consider, therefore, it may advantageously be employed for exploring roof-cavities, inasmuch as the chief danger in such cases arises from currents.

A. B.

The Safety-Lamps in use at Saarbrücken Fiscal Collieries.

(Zeitschrift für das Berg- Hütten-und Salinen-Wesen im Preussischen Staate, vol. xxxi., 1883, p. 52.)

1st. The Davy, in its unaltered and well-known construction. The wire forming the gauze is $\frac{1}{3}$ millimetre thick. The meshes are rectangular, and one hundred and forty-four go to a square centimetre. These lamps are only used by the officials for the purpose of examining the air, and then only in some districts.

2nd. The Saarbrücken lamp, which is a Mueseler without the inner chimney and the thereto-attached horizontal gauze. The oil-holder is much lower than in the Mueseler, being 37 millimetres high against 50 millimetres. The gauze is protected at the top by a copper cap, which fits tight over the gauze, and is perforated to the same extent as the gauze. The lower parts of the lamp, with the lower, middle, and upper rings, with plate, are of brass, and the upper parts of iron. The glass cylinder has a diameter (outside) of 65 millimetres, is 6 millimetres thick, and 65 millimetres high; is made of well-tempered white glass, of as even a thickness as possible, and accurately ground where it bears upon the plates. The wire forming the gauze is 3 millimetres thick, and one hundred and forty-four meshes go to a square centimetre. A round wick is used, and the oil is of pure rape-seed. The lamps are locked by a screw fitted at the bottom of the oil-holder. The total weight is 850 grains against 990 grains of the Mueseler, and 1,020 grains of the lamps mostly used in Westphalia.

3rd. Lately some of Dr. Schondorff's improved magnetic Bidder lock-lamps have been successfully used at the Heinitz Colliery.

C. Z. B.

On Winding from Mines with a Sheave instead of with a Drum.

By — Baumann.

(Zeitschrift für das Berg- Hutten- und Salinen-Wesen im Preussischen Staate, vol. xxxi., 1883, pp. 173–186.)

The winding by a sheave was first introduced by Mr. Köpe, at the Hannover Colliery (Westphalia), and consists in attaching a sheave, or pulley, to a winding engine, instead of the drums, around which the half or less of its circumference an endless rope passes.

The sheave is placed directly over the shaft. An endless rope in this way is said to have been in use at the Montrambert Mines[1] in 1858, but it was not used for raising, but for lowering material.

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[1] Bulletin de la Société de l'Industrie Minérale, 2nd series, vol. x., Grist, Sur les descendeurs de remblais des houillères de Montrambert.

Either the cages serve as a connecting link between the winding rope and the counterbalance rope, or there is only one rope which passes through the cages, the cages being held by patent caps.

Let P represent half the weight of the rope and the weight of the empty cage (inclusive of empty tubs or trams), and Q equal half the weight of the rope and the weight of the cage with coal and tubs, then sheave-winding can only be possible when

$$Q - P = \mu (Q + P).$$

In order to determine the coefficient of friction μ the Author made a number of trials upon sheaves, whose treads were lined with oakwood, leather, or cast iron, of which the following Table is an analysis: —

Wire Rope.			Tread of Sheave.			Number of Trials.	$\mu =$
Diameter.		Material.	Diameter.		Material.		
Millimetres.	Inch.		Metres.	Feet.			
16	0·63	Steel (old)	2·2	7·2	Oakwood . .	14	0·303
"	"	"	4·4	14·4	" . .	79	0·258
18	0·71	"	"	"	" . .	66	0·215
20	0·79	Iron (new)	"	"	" . .	21	0·280
"	"	Iron (old)	"	"	" . .	80	0·246
32	1·26	"	"	"	" . .	32	0·197
					A . .	292	0·242
16	0·63	Steel (old)	3·2	10·5	Leather, lying flat. . .	37	0·277
18	0·71	"	"	"	" "	46	0·244
20	0·79	Iron (new)	"	"	" "	52	0·253
"	"	Iron (old)	"	"	" "	20	0·230
32	1·26	"	"	"	" "	52	0·234
					B . .	207	0·248
16	0·63	Steel (old)	3·2	10·5	Leather, lying edgeways .	19	0·281
18	0·71	"	"	"	" "	14	0·267
20	0·79	Iron (new)	"	"	" "	15	0·269
"	"	Iron (old)	"	"	" "	24	0·228
32	1·26	"	"	"	" "	17	0·248
					C . .	89	0·256
15	0·59	Iron (old)	1·6	5·25	Cast iron .	99	0·227
21	0·83	"	"	"	" .	50	0·209
26	1·02	Steel (old)	"	"	" .	129	0·182
					D . .	278	0·203
					Average of all trials . .	866	0·232

The friction of the rope on cast iron is the least, upon wood greater, and a little greater on leather, especially when laid edgeways. The coefficient μ decreases with an increasing diameter of the rope (probably the thinner ropes make a deeper impression on the tread), and by an increasing load (the influence of the rigidity of the rope is less by small loads).

When the trials followed quickly upon one another the resistance to friction decreased, while after greasing and pauses it increased.

In actual practice the circumstances cannot be so unfavourable as purposely made in the trials, and the following figures can be taken as a basis:—

Wire-rope upon cast iron, $\mu = 0 \cdot 20$.
„ „ „ oakwood, $\mu = 0 \cdot 24$.
„ „ „ leather, $\mu = 0 \cdot 25$.

By an analytical mathematical inquiry the Author deduces formulas for the finding, 1st, the greatest useful load possible to wind under the existing circumstances; 2ndly, how heavy for certain loads a rope must be so that all danger from slipping when winding is avoided; and a number of Tables are given showing the least depth at which windings are possible with different lined sheaves, and under varying weight of ropes and ratios of net to gross load.

The Tables and calculations show that when the ratio of the dead load to the useful load is $1 \cdot 5$ (the average ratio) a sufficient resistance to friction can be obtained for winding at all depths when the rope only covers half the circumference of a lined sheave and five-fourths of a cast-iron sheave.

The increased surface of friction can be obtained by the use of rollers.

A brake is recommended to be used when men are raised, which should act in the sheave through the medium of the rope. Flat ropes would be preferable to round ropes with respect to greater braking surface, and also as a counterbalance, for they have not the tendency to twist and throw themselves into loops that round ropes possess.

The Author states that an unbalanced rope requires double the machine-power of a rope-balanced rope, without taking the friction resistance into account. An economy of plant, together with a saving of rope, is effected by a sheave and rope counterbalance.

By adopting an endless rope which passes through the cages, a winding can be carried on at different levels by shifting the cages on the ropes, and the rope can be better economized by shifting it as it wears.

A sticking of the cage on the shaft, or an overwinding, will not be so injurious to the rope with a sheave as with a drum, for in the former case the rope will slip on the sheave.

C. Z. B.

The Analysis of Explosives. By Dr. W. Hampe.

(Zeitschrift für das Berg- Hutten-und Salinen-Wesen im Preussischen Staate, vol. xxxi., 1883, pp. 107–133.)

Ordinary dynamite contains 25 per cent. of infusorial earth for absorption, which is an inexplosive and incombustible material, and reduces the explosive power 67 per cent. of the pure tri-nitroglycerine, as about eight parts of the latter are used in heating the infusorial earth when exploding. Explosive gelatine consists of 8 per cent. of gun-cotton, and 92 per cent. of tri-nitroglycerine. Its explosive power is not much less than that of the explosive oil. When that of the latter is represented by 1,380, that of the former is 1,350 (according to trials with Trauzl's explosive measurer).

Explosive gelatine is much to be preferred to dynamite, on account of its great safety in transport, storing, and handling; a blow of 3·5 kilograms (25·3 foot-lbs.) will not explode it; when slowly heated it explodes at 204° Centigrade (399°·2 Fahrenheit), and when quickly heated, at 240° Centigrade (464° Fahrenheit); while diatomaceous dynamite explodes with a blow of 1 kilogram (7·23 foot-lbs.), and on heating to 180° Centigrade (356° Fahrenheit). The composition of gelatine dynamite is as follows:—

Gelatine Dynamite.—I.

65 per cent. gelatinized nitro-glycerine	97·5	per cent.	nitro-glycerine.
	2·5	„	collodion wool.
35 „ of mixing powder . . .	75·0	„	saltpetre.
	24·0	„	cellulose.
	1·0	„	soda.

Gelatine Dynamite.—II.

45 per cent. gelatinized nitro-glycerine	97·5	per cent.	nitro-glycerine.
	2·5	„	collodion wool.
55 „ mixing powder	75·0	„	saltpetre.
	24·0	„	cellulose.
	1·0	„	soda.

The Author divides the chemical part of his Paper into two divisions. The first deals with the existing methods of determining the nitrogen in nitrogen compounds, besides the experiments conducted at the Clausthal Laboratory, and describes a new quantitative analytical method of determining nitrogen.

The second deals with the ways and means of quantitatively analysing and dividing the different nitrogen compounds. The methods of Dumas, Walter Hempel, Beckerhinn, Fillip Hess, Champion, and Pellet; and nitro-metric methods, containing a description of various nitrometers; together with results of analyses of saltpetre, gunpowder, gelatine, dynamite, gun-cotton, and tri-nitroglycerine, are detailed at some length in the first part.

C. Z. B.

Experiments with Mining-Explosives. By Dr. Klose.

(Zeitschrift für das Berg- Hutten- und Salinen-Wesen im Preussischen Staate, vol. xxxi., 1883, pp. 91–105.)

The fiscal collieries in Saarbrücken used, in the year 1881–82, 88,7457 kilograms (873·44 tons) of gunpowder, and 15,701 kilograms (15·45 tons) of dynamite, having a total value of £27,259. Assuming that the rest of the coal districts use a proportional amount of explosives, then the collieries of Prussia will have consumed in 1881 £225,000 worth of explosives. Pistol trial.—One of the conditions exacted by the fiscal authorities from the manufacturers of powder is that the powder must be made with pure nitrate of potash, and must contain at least 70 per cent. of saltpetre, including not more than 1 per cent. of chlorate of potash. The powder must be perfectly dry, and must not soil the hands. The power of the same must be equal to 18° or 20°. This had reference to an instrument called a pistol, which has attached to it a crucible for holding a small quantity of fine powder, to the lid of which pistol is attached a lever which moves a toothed wheel. On firing the powder the wheel is turned, according to the strength of the powder, measured in degrees of rotation of the wheel.

On account of the great difference of weight of equal cubic quantities of powder, owing to different sizes of the grain, this mode of trial has been dispensed with in favour of the other trials.

Rod trial.—This is a similar apparatus, but instead of a wheel the cover of the crucible has a rod attached, sliding upon guides, upon which the height can be measured to which the cover with the rod is thrown when the powder is exploded. This instrument was improved by substituting for the crucible and lid a cylinder and piston, for in the former case only part of the powder had effect on the lid, the rest being burnt away when the cover was raised. In a Table given by the Author, compressed powder being taken at 15·3 (the square root of the height the powder threw the piston with the rod); coarse-grained powder was 13·5; mixed-grained powder, 13·5, and fine-grained, 13·1.

Lead cylinder trials.—In this case the enlargement of a space in a lead cylinder by the explosion in it of powder, is the measure of the strength of the powder. A section of the cylinders after explosion shows effectively the force of the explosive, of which a plaster cast may be taken for preservation. Compressed powder (not really compressed, for its specific gravity was rather less than that of ordinary powder), gave good results in the lead cylinder trials. The lead trials proved that blasting with a space is not so efficacious as when the powder fills lightly the space allowed it. This is rather important, as the effect of an air-cushion has played for some time past an important part in the practice of blasting.

The specific and cubic weight of powders.—In the determining of

these quantities an apparatus devised by Major Bode, described in the text, was used. Four trials of one gunpowder gave a specific gravity of 1·6090, 1·6090, 1·6090, 1·6103, 1·6106. Four trials of another gave 1·6870, 1·68602, 1·68628, 1·6870. The granulating and polishing of powder has an effect upon its specific gravity, for the surface is made denser. Coarse-grained powder had a specific gravity of 1·5990; mixed-grained, 1·6093; and fine-grained, 1·6312, the powder being of the same composition in each case. The cubical weight depends upon the specific weight and the size of the grains, and is so far of interest to the mining man, for he generally measures, and does not weigh the requisite quantity. The following Tables give values of different powders:—

No.	Powder used.	Specific Weight.	Cubic Weight 100 cubic centimetres (6·1 cubic inches weight). Grams = 154 grains.	50 grams (771·6 grains) enlarged the Powder Space by cubic centimetres = 0·6 cubic inch.	Taking No. 1 Powder at 100, the others compare with it as follow—		
					Specific Weight.	Cubic Weight.	Enlargement of Powder Space.
1	St. Ingbert . . .	1·6198	109·0	145	100	100	100
2	V.R.W.P.F.K.B. No. 1	1·4899	97·3	224	93	89	153
3	V.R.W.P.F. No. 17. .	1·6871	107·3	163	104	98	112
4	Königswiesen . . .	1·5181	100·2	187	94	92	129
5	Bons, coarse grained .	1·5990	104·4	138	98	96	95
6	,, mixed ,, .	1·6093	111·6	147	99	102	101
7	,, fine ,, .	1·6312	106·2	175	101	97	120
8	Compressed powder .	1·5225	144·8	250	94	133	172

Dynamite.—The power of this explosive can be easily determined by Von Trauzl's plan. The following Table represents the explosive power of dynamite:—

Dynamite Tried.	Composition.	Capacity of Lead Cylinder.				
		Before Explosion in C. Cm.	After Explosion.			
			Trial I.	Trial II.	Trial III.	Mean.
1. Dynamite No. I. old	75 Nitro-glycerine . 25 Diatomaceous earth	50 =3·05 cub. ins.	C. Cm. 980	C. Cm. 920	C. Cm. 960	C. Cm. C. Ins. 953 = 58
2. Dynamite No. II. new	60 Explosive gelatine 40 Mixing powder .	50	1,200	1,200	1,250	1,217 = 74¼
3. Dynamite No. II. .	75 Explosive gelatine 25 Mixing powder .	50	930	950	970	950 = 58
4. Do. No. III. detonator .	25 Nitro-glycerine . 75 Mixing powder .	50	700	740	720	720 = 44
5. Do. No. III. cartridge .	15 Nitro-glycerine . 85 Mixing powder .	50	590	550	590	577 = 35
6. Explosive gelatine .	..	50	1,500	1,550	1,500	1,517 = 92½
7. Nitro-glycerine . .	..	50	1,790	1,750	17,901	1,777 = 108½

Comparisons of the power of dynamite and gunpowder cannot be relied upon when made with lead cylinder trials, for by them the former is sixteen times stronger than the latter, a result which does not agree with experience. The shape of the space of the lead cylinder after explosion by dynamite differs from that left by powder: the former enlarges the space at the bottom; the latter in the middle. Figures of the spaces are in the test. Trials made with tampings of water and sand show them to be of equal value.

Burnt-lime.—Comparisons were made with powder and lime in the lead cylinders. The lime was procured from two districts, powdered and immediately pressed by a pressure of 35½ tons. On account of the cartridges swelling when taken from the press, they were put into the lead cylinder without weighing.

—	The Blasting Chamber.		Enlargement.
	Before the Operation.	After the Operation.	
	Cubic centimetres.	Cubic centimetres.	Cubic centimetres.
Champigne chalk	130·8	138·0	7·2
Saar chalk	133·2	145·5	12·3

In mild soft coal this form of blasting may be possible, but certainly not with the Saarbrücken coal. Increased diameter of boreholes, difficulty of manufacture of cartridges, and transport of the same, and the difficulty of pumping effectually the water into lime, are obstacles which are not conducive to its general or even partial introduction.

C. Z. B.

Influence of Atmospheric Depressions on Fire-Damp in Coal Mines. By Emile Harzé.

(Annales des Travaux Publics de Belgique, vol. xxxix., 1882, pp. 51–59.)

The influence of variations of barometric pressure on outbursts of fire-damp in coal-mines, is a question about which mining engineers are not yet agreed; but the balance of authoritative opinion is strongly in favour of those who regard these variations as capable of bringing about disasters which often cannot be otherwise accounted for. Government inspectors have been directed to urge upon colliery managers the necessity of watching the movements of the barometric column, and laws have been enacted to compel observance of the recommendations made with regard to these changes of atmospheric pressure. Yet many engineers of high repute maintain that no appreciable effect, or at most no dangerous effect, can result from a sudden and great fall in well-

ventilated mines. It is objected that the volume of air passed through the ways per minute is so great that the light carburetted hydrogen invading the ways from the expansion of accumulations in the broken mine cannot enter fast enough to vitiate the current up to the explosive point. And calculations founded upon Marriotte's law are adduced in proof of this assertion. This view errs, however, in being too theoretical. It assumes that all the gas invading the air-ways is swept away by the ventilative current. Leaving out of consideration the fact that the ventilative current in some parts of the workings may be highly charged with gas given off from the working faces, and that a small addition would be sufficient to raise it to the firing point—like the drop of water that causes the already full vessel to overflow—the holders of this view may be shown to be in error by omitting to take account of some of the essential elements of the question. The velocity of the air-current is not the same at all points in the section of the ways. As a matter of fact, the sides and roof are not swept by the current; for they not only present great irregularities of surface, but offer a succession of recesses or panels formed by the timbering. In these spaces between two sets of timbers the air has little or no progressive motion. The gas, arrested by these projections, accumulates between the caps or head-pieces on the roof. In this way long trains of inflammable gas may be laid to any considerable accumulation that may exist—a condition of things that is obviously dangerous. Moreover, since the gas can escape but slowly from these situations, the danger may subsist even after the barometer has begun to rise again.

The Author concludes from a consideration of these facts; first, that a sudden fall of the barometer may bring about a dangerous state of things in fiery workings; second, that the calculations put forward by some engineers, who reject the possibility of such influence, are formed from a point of view which does not embrace all the elements of the problem; and, third, that during a rapid and deep fall, and until some time after the succeeding rise has set in, it is desirable to quicken the ventilation and to take extra precautions in blasting. This third conclusion leads the Author to remark that when the ventilation, whether of a whole district or of a special part of the workings, is increased for the purpose of allowing shots to be fired, it is prudent to delay firing for a time after the change is made, because an increased velocity of the air-current may draw out gas from existing accumulations, and carry it into the places where the blasting is to be done. The same effects, in a less degree, may be caused by the opening and shutting of doors, or the removal of any obstruction to the air-current. Mr. Cornet has directed attention to the fact that the high winds, which often accompany a deep fall of the barometer, appreciably diminish the action of ventilative apparatus.

G. G. A.

On Iron- and Manganese-Ores occurring in the Jabalpur District.

By F. R. Mallet, F.G.S.

(Records of the Geological Survey of India, vol. xvi., 1883, pp. 94 and 116.)

The Jabalpur district has long been known to abound in iron ores, and until the country was opened up by railways, bringing foreign competition into play, it was a great centre for the smelting of iron carried on by the native method. Since then European enterprise has found its way into the district, but has never come to any decisive action, owing to the difficulty of keeping the furnaces in blast with charcoal only, in the absence of any available coal. This difficulty, however, seems to be in a fair way of being surmounted, as workable coal has been found by Mr. T. W. H. Hughes at Umeria, in the immediate neighbourhood of the Jabalpur district, and a line of railway has been projected from there to Murwara (Katni) on the East Indian line.

According to a survey by Mr. C. A. Hacket, a band of iron-bearing transition strata, bounded on the north by Vindhyan sandstones, and on the south by Deccan trap, stretches eastwards for more than 200 miles through the Son Valley, and comes into contact with a thickly populated alluvial belt, through which the Narbadda flows westward. Of the great variety of rocks occurring in this belt it is only necessary to mention two, namely, the Bijáwar, or transition series, and the rock laterite, for it is in them that nearly all the iron ore is contained. The ores are almost exclusively varieties of hematite and limonite (or red and brown hematite), the former being characteristic of the Bijáwar—the latter of the rock laterite formation. They may be classified thus:—

- Bijáwar ores
  - 1. Hematite
    - Schistose hematite.
    - Micaceous iron.
    - Jasper hematite.
    - Semi-ochreous hematite.
    - Manganiferous „
  - 2. Limonite
- Laterite ores
  - 1. Limonite
    - Pisolitic limonite (breaking with smooth conchoidal fracture).
    - Pisolitic limonite (breaking with rough uneven fracture).
    - Ordinary laterite (parts of which contain a high percentage of iron).
  - 2. Hematite

Small crystals of magnetite have also been found disseminated through some of the hematite beds.

Bijáwar ores.—One of the most extensively worked clustres of mines or native workings is situated in the group of hills south of Sarroli Majgoan (8 miles south-east of Tehora), and it will be convenient to make this neighbourhood a starting-point for the

following descriptions: The hill ½ mile south of Agaria is flat-topped and wide, and about 100 feet high, and appears to consist entirely of iron ore. On the summit there is a thin skin of laterite, below which there are beds of very soft, crumbly, evenly laminated micaceous iron, interbanded with occasional argillaceous layers; but the greater portion of the ore constituting the lower beds is schistose hematite, which, although harder than the former, is easily worked on account of its fissile character. A rough estimate of the quantity of ore contained in this hill available by open workings with free drainage, may be taken at 4,000,000 cubic yards, or 14,000,000 tons. A sample of the schistose hematite from the northern side of the hill gave on analysis 97·54 per cent. of ferric oxide = 68·28 per cent. of iron. In a ridge 40 to 50 feet high, running westward from Agaria, a band of hematite schist several yards wide is visible, and as the *débris* of this ridge consist entirely of hematite, it may be assumed that considerably more iron ore exists than is apparent on the surface, but even if this is not the case the amount in the exposed strata is considerable. In the hills south-east of Agaria runs of Bijáwar limonite occur in one or two places, but no good section is visible. There are two hillocks, one ¾ mile, somewhat west of south, the other 1 mile south-south-west of Sarroli. The former is composed of schistose hematite and micaceous iron capped in some places with a thin skin of laterite; the northern part of the latter is also of iron ore, the lower beds of which are of hard micaceous iron passing into schistose hematite, while the upper strata are of soft, crumbly, finely laminated micaceous iron, interbanded with some argillaceous layers similar to the formation of the hill ½ mile south of Agaria. There are two large excavations in the upper beds known as the Sarroli and Partapar mines. A rough estimate of the ore available by open workings with free drainage may be taken at 500,000 cubic yards = 1,700,000 tons in each hill. This estimate, as well as the one before, does not include the ore which is available by open workings below the level of the surrounding country. A sample of the micaceous iron from the Partapar mine yielded 92·21 per cent. of ferric oxide = 64·55 per cent. of iron, and the harder ore from the north end of the hill gave 97·16 per cent. of ferric oxide = 68·02 per cent. of iron. About 1 mile south-east of Jauli (3 miles south-east of Sarroli) there is an extensive quarry of semi-ochreous hematite. The beds are vertical, and the exposed surface is approximately 150 feet thick, but the ore is interbanded with quartzose layers varying from a fraction of an inch to several inches. The water when it does not evaporate more quickly than it enters the workings, soaks away, so that there is no difficulty as to drainage. A quarry ¼ mile north-east shows a section of the same ore, and it is supposed that a continuous band exists between these two workings. An average sample of the Jauli ore yielded 75·69 per cent. of ferric oxide = 52·98 per cent. of iron. By aid of picking, however, 97·86 per cent. of ferric oxide = 68·50

per cent. of iron can be obtained. The hills of the Lora range (east of Tehora) are composed of alternate layers of micaceous iron and red jaspery quartz, the greater portion of which is too siliceous to be smelted with advantage. Some workable schists of this ore exist just north of Mongola, but they are not sufficiently exposed to enable an opinion of their extent to be formed. On the southern slope of the hill ½ mile south of Gogra numerous shallow pits have been sunk into layers of manganiferous micaceous iron interbanded with jaspery quartz. The strata are concealed beneath the talus so that no estimate of the quantity can be formed, but judging from the *débris* the amount of ore available by dry open workings must be considerable. The proportion of manganese varies much, and a large part of it occurs as psilomelane in irregular segregations or minutely disseminated through the rock. A sample carefully taken from different pits yielded 66·33 per cent. of ferric oxide = 46·43 per cent. iron, and 12·26 per cent. of manganese (with traces of cobalt). The ore from these pits produces a hard steely iron, while that from the Sarroli neighbourhood yields a soft material. In a ridge running eastwards of Kuthola a similar manganiferous hematite schist with psilomelane is visible, but no good surface is exposed. On the northern slope of the hillock by Gosulpur, a strong band of manganiferous micaceous iron outcrops. The thickness of ore actually visible at the foot of the hill is about 50 feet, and can be fairly seen running west 30° south for about ⅓ mile, and may be followed, in occasional outcrops, for another ¼ mile. Unless this band thins out immediately westward of Gosulpur, some hundred of thousand tons of ore are available by open dry workings, and probably many millions more by going deeper. The appearance of the rock shows that here too the proportion of manganese is very variable, but although part of it occurs as psilomelane in segregations, enough of it is disseminated through the rock to make the ore here, as well as that of Lora, a suitable material for the manufacture of Spiegeleisen. Just below the outcrop of manganiferous ore on the same hillock, there is a band of limonite 15 feet thick, running parallel with the other ores for about the same distance, containing however a high percentage of phosphorus, *i.e.*, 81·57 per cent. of ferric oxide = 57·10 per cent. iron, and 1·69 per cent. of phosphoric acid. Some old holes near Gosulpur have exposed a section of about 2½ feet of manganese ore, chiefly pyrosulite with some psilomelane, below which there are 6 feet of laterite containing some nodules of the same ore. With a view to testing the richness of the deposit, a shaft was sunk on the above site, but 9 feet from the surface all trace of the ore disappeared, and a disintegrated quartz schist was reached. The formation here appears to consist of a layer of laterite, into which the manganese has filtered in a chemical solution, deposited on a floor of irregularly denuded Bijárvar rocks. In the Author's opinion this layer, although most likely subjected to many irregularities, contains a considerable amount of ore, which could be got

at by following up the deposit laterally from the present shaft. The pyrolusite and the psilomelane of this neighbourhood give 83·20 per cent. of available peroxide.

Laterite ores.—There are two main varieties of pisolitic ore; the fracture of the one is lustrous, smooth, and conchoidal, of the other dull, rough, and uneven. They occur on a horizon near the base of the lateritic strata. The bottom beds of this group are formed of rounded bits of quartz in a ferruginous paste, over which are beds of fine ferruginous sandstone; resting on these are several feet of oolitic iron ore covered by red and white and purple clays interbedded with coarse ferruginous sandstone, the whole being capped by ordinary laterite. In the neighbourhood of Bijori there are many small pits exposing a section of ore as below:—

——	Pisolitic Limonite, with Conchoidal Fracture.	Pisolitic Limonite, with Rough Fracture.	Non-Pisolitic Limonite.	Hematitic Ore.	Total.
	Feet. In.	Feet. In.	Feet. In.	Feet. In.	Feet. In.
¼ mile south 15° west from Bijori	1 2	4 2	..	..	5 4
1 mile south of Bijori . . .	1 3	3 7	..	..	4 10
North side of Bijori	..	3 4	..	..	3 4
½ mile east of Bijori	..	2 0	..	..	2 0
300 yards north of Bijori . .	0 8	2 9	..	..	3 5
½ mile south-west of Majhgaon .	1 6 ?	..	..	4 0	5 6
South-west side of Majhgaon .	..	2 0	..	..	2 0
¾ mile south-west of Bhadora .	..	3 0	0 10	..	3 10

The Author is strongly inclined to think that the iron-bearing strata are continuous throughout the district, although the details of the section may vary. At any rate there must be an immense quantity of ore available, as a continuous bed of even a yard thick would contain more than one million tons to a square mile. At about a mile north of St. Emilia there are two quarries exposing a section of pisolitic iron ore under about 2 feet of ferruginous sandstone and laterite. The floor of the workings is still on the ore, so that the total thickness of the layer is not apparent. The ore consists of spherules of limonite imbedded in a semi-ochreous cement of red and brown ferric oxide. An average sample gave: ferric oxide, 77·81 per cent. = 54·47 per cent. of iron; peroxide of manganese, 1·54 per cent.; and phosphoric acid, 0·82 per cent. Near Jhijri and Kailwara bands of pisolitic limonite, with conchoidal fracture, are visible, varying from 10 to 20 inches in thickness. Near Murwara a mass of earthy limonite, with 75·23 per cent. of ferric oxide, has been found. The Kanhwara hills (6 miles north-east of Murwara) form a sharply defined level plateau. The surface-rock is ordinary laterite, while bands of rich ore outcrop along the face of the slopes. Through means of numerous pits and outcrops, the

Author has traced three distinct seams through the plateau, consisting chiefly of pisolitic limonitic, with conchoidal fracture; also ochreous, oolitic, limonitic, and ferruginous sandstone interbedded. The average thickness of the top seam is estimated at 2 feet 6 inches, that of the two lower at 2 feet. The area of the plateau is about 2½ square miles; the top seam would therefore contain about 19,000,000, the two lower ones 15,000,000 tons of ore each. The greater part of the top seam is available by open workings; the rest by adits or shallow shafts.

Most of the ordinary laterite above mentioned contains a high percentage of iron (a sample taken near Kailwara gave 63·27 per cent. of ferric oxide), and in a less favourable country would be of considerable value.

Besides the localities above mentioned, there are many others in the Jabalpur district, at present too remote to be worked, where large quantities of ore are known to exist. Superior limestone eminently suitable for flux can be had in the immediate vicinity of Murwara, and should this become exhausted, or should the alluvial deposits by which it is covered become too thick to allow of such being quarried, a practically unlimited supply of the same mineral can be had from the neighbourhood of Bijeraghoghar, whence a tramway might be built to Murwara, which would also serve the Kanwhara Hills mining district. Aluminous laterite can be had abundantly in the hills south-west of Murwara, which could be used for an aluminous flux should such be required. Dolomite, for converter linings, can be had in great abundance from the well known marble rocks about 2 miles from Mirgan Station on the Great Indian Peninsula Railway. Good fire-bricks have been made of the clays found near Jabalpur and Andari, a village 14 miles south of Chandia, and the coal measures of Umeria are also expected to contain fire clay.

In conclusion the Author thinks that Murwara, owing to its central position, direct railway communication, and abundant water supply, would prove an excellent site for future ironworks on an extensive scale.

H. L. L.

Blast-Furnaces at Roanoke, Virginia. By J. P. WITHEROW.

(Transactions of the American Institute of Mining Engineers, June 1882.)

The Crozer Steel and Iron Company, of Roanoke, Virginia, adopt the following dimensions and quantities as a basis of calculation in determining the capacity or output of a furnace, and the size of its boiler, engine, and draught-stack. For anthracite furnaces, 60 square feet of fire-surface in boilers are allowed to produce 1 ton of iron in twenty-four hours; therefore 6,000 feet of fire-surface will supply steam to make 100 tons of iron in twenty-four hours. For coke furnaces, 40 square feet of heating surface are allowed for 1 ton of iron in twenty-four

hours, or 4,000 square feet for 100 tons in that time. For charcoal furnaces, 30 square feet for 1 ton, or 3,000 square feet for 100 tons of iron in twenty-four hours are allowed for heating surface. This is on the assumption that the temperature of the blast will range between 1,300° and 1,500° Fahrenheit. By the same method it has been determined that 140 cubic feet of air per minute of piston-displacement will make a ton of iron in twenty-four hours with 50 per cent. ores, if not too siliceous, at a temperature of blast given above; therefore 14,000 feet per minute will make 100 tons of iron in twenty-four hours. In charcoal furnaces, on the same ores and at the same temperature, it is calculated that 110 cubic feet a minute will make 1 ton of iron in twenty-four hours, and that, therefore, 11,000 feet per minute will make 100 tons in that time. It is, moreover, assumed that the chimney or smoke-stack must have a capacity sufficient to carry off 15 tons of gas, the products of combustion, for every ton of iron the furnace is required to make.

The Author thinks that blast-furnace engineers should establish a system of running the furnace by the temperature of the escaping gases. This temperature indicates the changes more quickly than the cinder or iron. Other things being equal, the hotter the blast the cooler the top, and *vice versâ*, and the increase of temperature at the tunnel head will sooner indicate to the manager a derangement in furnace action than anything else. As the temperature of the higher zones increases, it will show that there is either an inadequate amount of ore and lime for the ascending gaseous currents and carbonic oxide to act upon, or it will show that the furnace is beginning to cement and scaffold, and prompt measures can be taken to remedy the difficulty.

G. G. A.

Cast-Iron of Unusual Strength. By Edward Gridley.

(Transactions of the American Institute of Mining Engineers, June 1883.)

The Author directs attention to some samples of cast iron of unusual strength, made at the Wassaic furnace, Duchess County, N.Y., from carbonate ore mined in that locality. The earliest samples were made from a mixture of two-thirds of this carbonate and one-third of Chateaugay ore. These showed a tensile strength of 32,014 lbs. per square inch in one instance when a test was made, and 34,176 lbs. in another instance of similar testing. After the stock of Chateaugay ore was exhausted, one-third raw carbonate was used, with two-thirds of roasted carbonate, and the first test made of the iron produced showed a tensile strength of 40,008 lbs. to the square inch. Later tests on samples made with carbonate ore alone have shown the following strengths: 39,669 lbs., 40,816 lbs., 41,882 lbs., 42,281 lbs., 39,902 lbs., and 40,130 lbs. A sample taken from the same bed of iron as the last-mentioned, and tested on another machine, broke with 40,151 lbs. per square

inch. Another sample from the same lot, tested by Professor R. H. Thurston, showed a strength of 40,000 lbs. Other samples, tested on a Thurston torsion machine, gave torsion 7°, and tensile strength 44,500 lbs.; and torsion 9° and tensile strength 47,500 lbs. per square inch. The average of thirteen tests, made by different persons, was 41,349 lbs.

These tests were all made from iron cast in the pig-bed direct from the furnace. Some were made from the full pig turned down, but most of them from samples obtained by making a hole in the sand at the end of the pig, from 10 to 20 inches long, and about 1¼ inch in diameter. No tests have yet been made from the re-melted iron. The following are analyses of the roasted carbonate and of the pig iron:—

ROASTED CARBONATE.

Silica	8·240
Peroxide of iron	77·202
Alumina	2·768
Red oxide of manganese	3·005
Lime	1·650
Magnesia	1·167
Phosphoric acid	0·275
Sulphur	0·224
Loss by ignition	5·684
Metallic iron	54·042
„ manganese	2·165
Phosphorus	120

PIG IRON.

Graphite	2·310	
Combined carbon	0·780	
		3·090
Silicon		1·307
Sulphur		0·086
Phosphorus		0·294
Manganese		1·512
Iron		93·700
		99·989

G. G. A.

On the Production of Stanniferous and Antimonial Lead at Freiberg. By C. A. PLATTNER.

(Jährbuch für das Berg- und Huttenwesen, im Konigreich Sachsen, 1883, p. 1.)

Since the abandonment of the barrel amalgamation process in Freiberg, and the introduction of sulphuric acid manufacture, as an accessory to the smelting processes proper, large quantities of pyretic ores, which formerly were only smelted with the slags, are now passed through the ore-furnaces, which results in the produc-

tion of lead with a small quantity of tin, which in its turn is separated in the dross or Abstrich of the softening furnace. The treatment of this and similar products containing arsenic and antimony has been the subject of numerous experiments extending back to the year 1870, and in 1881 the process described below was introduced by the Author. It includes the following operations:

1. *Desilvering Tin-dross* (Zinn Abstrich).—This product, though occasionally variable in composition, averages with the inclusion of 24 per cent. of entangled metallic particles—

Oxide of lead	70·35
Oxide of tin	12·53
Antimonic acid	12·50
Arsenic acid	4·75
Cupric oxide	0·61

It is discharged in a lead-improving furnace by fusion with about 5 per cent. of coal in order to reduce as much of the lead oxide as possible. The charge of 10 cwt. is kept melted until it rises to the level of the top of a dam placed across the door, which is then broken through to allow the liquified oxidized matter to escape, while the lead remains in the sump and accumulates as successive charges are smelted, until the furnace is completely filled. The lead is then tapped with the exception of 20 or 30 cwt., which are left to protect the furnace-bottom. The quantity of material smelted is about 4 tons daily, with 40 per cent. of its weight of coal, which gives 53 cwt. of discharged tin-dross and 46 per cent. of lead averaging 0·4 per cent. of silver; but with so much arsenic and antimony as to be very hard, and to require softening before cupellation.

2. *Revival of the discharged Tin-dross.*—The product of the first operation, averaging lead 58, tin 11·5, antimony 14·5, arsenic 7, and copper 0·2 per cent., is passed through a blast-furnace with four or eight tuyeres, with an addition of one and a half times its weight of slags, either from the subsequent operation or from the same process, and with a consumption of 25 per cent. of coke, gives about 55 per cent. by weight of a stanniferous lead (No. 1 tin-lead), containing tin 11·8, antimony 10·3, and arsenic 3·5 per cent., about 20 tons being passed through the furnace daily.

3. *Refining Tin-lead, Alloy No. I.*—A charge of 20 tons of the metal from the preceding operation is melted in a refinery furnace, and exposed at a red heat to a blast of air introduced at the side of the fire-bridge. This causes the tin to be more completely oxidized than the other metals, and to separate as a powdery dross (Zinnpuder No. 1), which, as it forms, is raked off the surface of the bath at intervals. As soon as the tin is separated, the metal begins to fume from the oxidation of the antimony, which combines with the lead oxide, and ultimately fuses into the ordinary antimonial black litharge, when the metal is

practically free from tin, and is an antimonical lead averaging, antimony 15, arsenic 1·0, and tin 0·5 per cent., and is tapped off. 70 per cent. of tin-lead No. 1 give 57 cwt. of antimonial lead, with a consumption of 20 cwt. of coal, and 15 cwt. of lignite.

4. *Revival of Tin-Powder No. I.*—This product, which contains lead 63·83, tin 10·85, antimony 11·89, arsenic 3·0, and copper 0·56 per cent., is too poor in tin to be smelted for the direct production of a saleable tin-lead alloy. It is therefore passed through a blast-furnace with twice the quantity of slags from operation 2, which already contains some tin, and therefore tends to prevent further loss of that metal. The working of the furnace is also rendered easy, the large quantity of slags tending to keep the furnace open in spite of the dense powdery character of the material melted. The products from 150 cwt. smelted daily, are 108·75 cwt. (72·5 per cent.) of revived tin-lead No. II., with a consumption of 60 cwt. of coke.

3. *Refining Tin-lead No. II.*—This is conducted in a softening-furnace in the same manner as described in operation 3. The oxidized product first produced, is of a grey colour, owing to the large amount of tin oxide contained, that subsequently produced being yellower and ultimately blackish grey, and passing into antimoniacal litharge. The refuse antimonial lead containing antimony 18, arsenic 1, and tin 0·5 per cent., goes to the antimonial lead smelting proper. The yellow and black dross is revived as in operation 4, while the grey oxide, Zinnpuder II., is revived for the production of tin-lead alloy. The average composition is—

Lead	44·74	49·86
Tin	27·59	24·28
Antimony	13·22	11·97
Copper	0·95	0·40
Arsenic	2·72	0·90
Oxygen and earthy matter	10·78	12·46

6. *Revival of Tin-dross No. II.*—This is effected in a small blast-furnace 2 metres high of trapezoidal section, 600 millimetres wide behind, and 400 millimetres in front, with two cast-iron twyers in the back wall. The hearth is made up with coke and clay mass moulded to a sump 320 millimetres deep in the centre, with an open gulley in front, the molten products running continuously into a conical cast-iron pot in front where the slag and metal separate. The tuyeres plunge at an angle of 10°, so that the blast and the jet of flame from the open hearth are driven over the iron gulley to prevent the reduced metal from chilling as it flows out. The whole furnace is placed under a capacious sheet-iron hood, connected by a pipe to the wall and condensing-chamber. After the furnace has been carefully dried, a bed of coke 500 millimetres deep is formed, upon which the tin-dross is charged with coke in the proportion of 10 to 3, the burden being subsequently increased to 10 to 2, and as almost immediately after, as the blast is turned on, the reduction commences. The pressure is

15 millimetres, if necessary, the nozzles are 20 millimetres in diameter. The operation is carried on with a fire not too bright at the throat, where lead-smoke and arsenical fumes are evolved in quantity, as well as at the open slag-breach. These are stopped by the hood, and pass into the condensing-chamber. In about two hours the sump is filled with metal, which then overflows by the gutter into the receiving-pot, whence it is ladled out from time to time. A small quantity of very tough slag, formed from the coke-ash and wear of the furnace bricks, &c., is lifted off from the surface of the metal. The charging of fuel and powder takes place alternately, 5 lbs. of the former broken to the size of a hen's egg, to 25 lbs. of the latter. 35 cwt. of dross are passed through the furnace daily, producing 26·5 cwt. (75 per cent.) of tin-lead alloy.

The slags contain, after deduction of 15 per cent. of intermixed metal: silica 28·65, tin oxide 20·40, lead oxide 5·81, cupric oxide 0·15, ferrous-oxide 26·61, manganous oxide 0·37, zinc oxide 0·70, alumina 12·0, lime 3·15, magnesia 0·79, sulphur 0·08 per cent. On account of the large amount of tin (about 15 per cent.), they are added to the furnace charges in the revival of the tin-dross No. 1 (operation 4). The chief difficulty in this operation is keeping the furnace clear from accretions at the tuyeres and breach, which form very rapidly if not prevented, on account of the refractory character of the slag. With proper care, however, the furnace may be kept in blast for several weeks in succession, small repairs being made in the hearth and tuyeres when necessary.

7. *Remelting Tin-lead alloy.*—This is effected in cast-iron pots of 15 tons capacity, the object being to obtain an alloy of uniform composition. The metal of the preceding operation is remelted as quickly and at as high a temperature as possible, to prevent any large formation of dross. The small amount of scum formed, about 7 per cent., is removed by perforated ladles, and together with all other waste, is returned to operation No. 4. The metal after skimming is cast into blocks as required for sale, and contains: tin 33, antimony 14, and arsenic 1 per cent.

It is of a greyish white colour, has a finely granular fracture, and may be usefully employed as a bearing metal as well as for small metal castings.

The remelting of 100 cwt. of metal is effected in four hours, with an expenditure of 12 cwt. of coal, and 5 cwt. of lignite.

8. *Cleaning Tin-slags.*—This applies to the treatment of the slags of the operation No. 4, which are too rich to be thrown away at once. About 25 tons are passed daily through a blast-furnace, with 20 per cent. by weight of coke, no flux being used. The products are: 26 cwt. of tin-slag lead, with tin 32, antimony 14·6, and arsenic 0·7 per cent., which is remelted for sale without further refining, and slags, which are thrown away. These contain, according to two analyses furnished by the Author, from 5·3 to 8·8 per cent. of oxide, or 3·9 to 6·6 per cent. of metallic tin.

In 1881 the following products were obtained per 100 cwt. of original tin dross smelted:—

46·27	of lead, from the desilvering operation.
33·10	antimonial lead from the tin separation.
19·33	tin-lead alloy from the final melting.
98·70	total.

Assuming the original material to contain 8·5, and the final alloy 33·5 per cent. of tin, there are accounted for in the latter 638 lbs. out of 850 lbs. of tin in the furnace, showing a loss of 212 lbs. or 24·4 per cent., which, considering the numerous processes involved, and the simultaneous production of merchantable antimonial lead, must be regarded as a satisfactory result.

Production of Antimonial Lead.

The second part of the memoir commences with a retrospect of the methods adopted at different times since 1829, for the treatment of antimonial litharge, and then discusses the method now adopted, which comprises the following operations:—

1. *Desilvering Antimonial Litharge.*—This is effected in a lead-softening furnace, and, like the first operation of the previous process, consists in a partial reduction with carbon, 38 per cent. being revived as hard lead, with 0·3 per cent. of silver, while 60 per cent. remain as desilverized litharge, with 10 to 14 per cent. of antimony. The quantity treated is 7 tons daily, with an expenditure of 20 per cent. of fuel.

2. *Revival of Desilverized Antimonial Litharge.*—This is done in an ordinary blast-furnace, 450 cwt. with an equal quantity of poor lead-slags, or those from the same operation, being smelted daily, with 18 per cent. of coke. The yield is 70 per cent. of antimonial lead, averaging antimony 18, arsenic 3·0, and tin 0·4 per cent.

3. *Remelting Antimonial Lead.*—The whole of the different kinds of antimonial lead produced in the operations previously described, assorted according to their richness in antimony, are melted in an iron pot holding 15 tons, and poled for four hours with a green-wood pole, during which arsenic is volatilized, the foreign metals are partly oxidized, forming a scum, which is removed by a perforated ladle, and an intimate mixture of the different alloys is obtained. The refined product containing antimony 15, arsenic 2·5, and tin 0·3 per cent., is then cast into pigs for sale. 100 cwt. of antimonial lead give 85 cwt. of refined metal, or 15 cwt. of skimmings or dross. The operation lasts seven hours, and requires 6·5 cwt. of fuel (coal and lignite).

4. *Liquation of Antimonial Dross.*—The skimmings obtained during the poling operation, are now subjected to liquation in a lead-refinery furnace, and yield 75 per cent. of antimonial lead,

and an annealed product containing a notable proportion of tin, which is sent to the second operation of the first process.

5. *Cleaning Antimonial Slags.*—The slags of the different reviving operations are smelted once or twice in a blast-furnace, either alone or with an addition of 10 per cent. of limestone. They yield about 15 per cent. of antimonial slag lead and poor slags, with about 2½ per cent. lead, which are thrown away.

The total quantity of ore-furnace lead subjected to the improving process at Freiberg, is about 10,000 tons yearly, giving rise to the following quantities of oxidized dross (*Abstrich*):—

310 tons	Stanniferous dross.
395 „	Arsenical „
307 „	Antimonial „
695 „	Litharge.

The first two items produce 60 tons of tin-lead alloy, and 210 tons of antimonial lead.

H. B.

Almaden Quicksilver Mines.

(Preussiche Zeitschrift, 1878, p. 125.)

Introduction and General Description.—The method of working these mines differs little from that first introduced in 1803 by Larrañaga; in fact, some of the earlier descriptions of Almaden, especially that by Noeggerath, are in most cases adapted to the present condition. The formation and situation of the lodes have not, however, as yet been described.

No traces of Roman workings having been found, it would appear that, although the Romans exported a good deal of cinnabar from the Spanish province Beatica, Almaden was unknown to them. The town of Almaden lies about 10 kilometres to the north of the Almadenejos station on the Ciudad Real—Badajoz line, and can be reached in two hours from the station. The town lies on a long chain of small hills, running from east to west, on the eastern slope of which, and quite near the town, are situated the shafts, the metallurgical works lying nearer the valley. The geological formation of the country is chiefly Silurian and Devonian; and principally on the north side of the town, many outcrops of Devonian can be traced in the Silurian formation of the Sierra Morena. This fact has been clearly established by many fossils belonging to the Devonian formation. The strata which most commonly occur round about the mines are as follow:—

1st. A greyish-white sandstone, very finely grained.
2nd. Quartzite, which darkens in colour on contact with the schist.
3rd. A foliated schist, which appears in close proximity to the mineral.

Plutonic rocks are represented by a sort of dioritic porphyry, to be found to the north of San Nicolas shaft, and the typical Almaden rock, "Piedra Frailesca," composed of shining black grains, cemented together by a calcareous dolomitic mass; according to researches instituted by Helmacken, the former may be classed with the Diabases, and the latter with the "Schalstein," or tabular spar.

Mining is carried on, on three courses of ore, called respectively San Nicolas, San Francisco, and San Pedro y San Diego; the last, as the name indicates, was separated nearer the surface. The body of ore, east of the principal section at San Teodoro, is, however, still called San Diego; whilst that situated to the west is called San Pedro. Burat mentions a fourth body of ore, situated more to the south, called Santa Clara, in his "Theorie der Erzlagerstetten;" this, however, disappears in lower levels. The run of the lodes is from east to west, the dip almost plumb; in some cases, however, they dip slightly to the north, and in San Pedro y San Diego sometimes to the south.

Faults are only observable in three places; two of these throw the San Nicolas lode, the one 2 metres to the north, and the other one (situated 12 metres to the east of the former) 3 metres to the south. No disturbance is, however, noted in the San Francisco lode, which is only 10 metres south of these faults. The third fault pushes the western part of San Pedro 2 metres to the north, and afterwards crosses the two other masses, without, however, altering their positions. In all three lodes the ore is found as an impregnation of the original strata, with cinnabar and metallic quicksilver; they can therefore neither be looked upon as seams nor veins, as the stratification of the original strata can still be observed within the limits of the impregnated parts.

San Pedro y San Diego is the largest, as well as richest, course of ore in the mine. Its south wall is formed by a stratum of quartzite, from 3 metres to 5 metres thick; still further south comes black schist, whilst 36 metres to 40 metres further occurs the San Teodoro shaft, sunk in Piedra Frailesca. The north wall of the lode is formed by a band of schist about 5 metres wide, extremely soft and crumbling on contact with the mineral; this is again followed by quartzite. Between the schist and quartzite lies the ore, carrying strata of grey sandstone; varying very much in width, it attains its maximum width at from 8 to 8½ metres, on the tenth floor of the San Diego level. West of San Teodoro shaft, that is to say, in the San Pedro level, the average width is 5 metres. In the upper floors, however, wider places can be observed; for instance, on the seventh floor at San Diego, the lode attains a width of 14 metres. The impregnation of the cinnabar gives the sandstone a light-red colour, and is in some places quite uniform; in others, however, it is so irregular that, even in pieces the size of a fist, different grades of impregnation can be observed, noticeable on account of the dark and light shading. The average percentage of mercury varies between 19 and 25 per cent.; but in

many places, and particularly on the south wall, it gets a good deal poorer.

The best idea of the richness of cinnabar can be had after the smelting, by the brittleness or hardness of the residue, as the higher the percentage rises the more porous and pulverizable is the residue. With rich ore the only residue is a thin, loose sand; whilst very poor ore gives hard and solid sandstone. It is thus shown that, in the formation of these deposits, the impregnation matter has, so to speak, pushed asunder the sandstone, and in some cases even taken its place. In the cracks and druses crystals of cinnabar are found, mostly small and ill-formed, together with iron pyrites and metallic mercury; in Pedro y Diego, however, the latter is found less than in the other lodes.

The walls of the lode, especially when in conjunction with quartzite, are not sharply defined; in fact, the sandstone gradually becomes quartzite, and the percentage in cinnabar gets poorer and poorer. The same thing occurs in the eastern and western ends of the deposit, the mineral-bearing stratum gets gradually poorer, till at last not a trace of cinnabar can be found.

The length of Pedro y Diego is about 180 metres.

San Francisco y San Nicolas are only divided by a band of quartzite, and differ greatly in character from San Pedro y Diego. The impregnated stratum does not consist of sandstone, as in Pedro y Diego, but is composed of quartzite, blackish in colour, and little stratified. This quartzite is traversed in all directions by small veins of cinnabar, only a few millimetres in width, often running parallel; so that in a small piece many of these veins can be descried, only separated by a band of quartzite 0·01 metre in width; hence the impregnation cannot be said to be equal in all places. In hollows and druses many small cinnabar crystals are found, as well as copper and iron pyrites, and small drops of metallic mercury. The average percentage in the San Nicolas lode is between 8 and 13, and can be fixed at 10 per cent.; in San Francisco it is about 8 per cent., the poorest ores smelted having a percentage of 2. The length of the San Francisco lode is about 180 metres, and the lode can be said to have increased in width in lower levels; the average width attained on the tenth floor lies between 4 and 6 metres.

The San Nicolas lode is considerably longer in the lower levels than near the surface, having only a length of 50 metres; it gradually lengthens to 200 metres on the tenth floor. On the tenth floor the width has increased towards the west to 15 metres, but the average is 6 metres, and in upper levels 8 metres. The north wall of the lode is formed of a thin stratum of schist, but after that dioritic porphyry.

The Method of Working these mines at the present time is almost the same as described by Larrañaga. The mining operations are divided into three periods; during the first, the lode is worked on its whole length, on a width of 2 metres, by overhand stoping down to the lowest floor, leaving thus a good deal of ore on each

side. During the second period the ore on one side is won, from the bottom upwards by perpendicular cuttings 4 metres wide, pillars of 4 metres being left standing, these cuttings being filled by masonry-walls, keeping step with the advance. In the third period the reserves of ore between the two walls are worked from the top downwards.

This method is very complicated and expensive on account of the walling; every year 2,500 cubic metres of wall are built, at a cost of from 10 to 12 francs per cubic metre; besides this, from 10,000 to 15,000 francs' worth of wood is used yearly.

Some improvements have been introduced lately; for instance, the transport of ore is to take place in the next deepest floor, and not to be lifted in kibbles to the next highest, as before. The gallery joining San Francisco to San Pedro has also been made the principal extraction gallery, so as to enable the ore to be hoisted with greater facility from all the shafts. At every 40 metres cross-cuts are driven into the different lodes from this gallery, which is shown on plan. The transport on the tenth floor is now done by wagons running on rails, whilst before it was done by wheel-barrows; at the present moment attention is directed to arranging the tenth floor, which San Nicolas and San Francisco have not yet reached, and San Diego only partly.

Lately the mining operations were limited to the removal of the mineral reserves left in the pillars.

Of the three shafts, only two, namely, Teodoro and Miguel, are sunk to the level of the tenth floor, which lies 285 metres under the surface. The principal extraction-shaft is San Teodoro, which has a 40-HP. engine; after each shift iron buckets holding 1 cubic metre are let down into the sump, each time lifting about 0·3 cubic metre. San Miguel has an engine of 20 HP., which is also used for the hoisting of water and ore. San Aquilino is principally used for bringing material into the mine, and the conveyance of men.

The total extraction is 18,000 tons a-year.

J. A.

On a New Theorem in Dynamic Electricity.

By L. Thévenin.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcvii., 1883, pp. 159–161.)

Given a known system of connected linear conductors, including known electromotive forces E_1 E_2, ... E_n, two points are taken as A and A′ possessing potentials V and V′. If the points A and A′ are connected by a wire A B A′ of resistance r, containing no electromotive force, the potentials of the points A and A′ take values differing from V and V′, but the current i which circulates

in the wire is given by the formula $i = \frac{V - V'}{r + R}$, in which R represents the resistance of the primary system, measured between the points A and A′ considered as electrodes. Ohm's formula is thus applicable, not only to simple electromotor circuits, presenting well-defined poles, but to a net-work of conductors that may be considered as an electromotor with arbitrary poles, of which the electromotive force is, in each case, equal to the difference of potentials pre-existing at the two points chosen as poles. This theorem, which has not hitherto been pointed out, is very serviceable in certain theoretical calculations, and in practice it admits of immediately evaluating, by means of two data easily obtained experimentally, the quantity of current traversing a branch circuit that may be connected on to a net-work of conductors, without intimate acquaintance with the constitution of the net-work. The Author demonstrates the theorem.

P. H.

Determination of the Internal inert Resistance of an Electric System with Perturbing Internal Electromotive Forces.

By G. Cabanellas.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcvii., 1883, pp. 311–313.)

Mr. L. Thévenin expresses [1] generally a theorem formulated as a particular case in dealing with shunted batteries by Mr. Pollard. The following enunciation of the theorem appears to the Author to be at once more general and explicit:—If any electric system, in a permanent state of tension, is connected by any two of its points to any second electric system, there can, without modifying any of the effects of the first system on the second, be effected a reduction, between the two points, of the first system to the simple expression of a resistance equal to the inert resistance of the system between these points, and to an electromotive force equal to the difference of primary potentials of the two points of the first system. The Author gives a method of measuring the inert resistance of simple or complex systems, applicable either with the Wheatstone Bridge or when two galvanometers are at disposal. Let R be the inert resistance of the system between the points A and B of potential V_A and V_B measured on open circuit; let $e = V_A - V_B$. Close the circuit with an external resistance r in which is an electromotive force E tending to produce a current of contrary direction to e. Call R_E the apparent or effective resistance observed by direct measurement, by the bridge or with two galvanometers, during the action of the internal force e. If ϵ and i are

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[1] Ante, p. 381.

the effective difference of potentials and the effective quantity during the measurement, $R_x = \frac{\epsilon}{i}$, but as

$$\epsilon = e + R\,i,\ R_x = R + \frac{e}{i};\ \text{or}\ i = \frac{E - e}{r + R},\ \text{and}$$

$$R_x = R + e\,\frac{(r + R)}{E - e}.^{2}$$

A second measurement with an external resistance r' and an electromotive force E' will give $n' = \frac{E'}{e} = 1 + \frac{r' + R}{R_x' - R}$. And it follows since $\frac{n}{n'}, = \frac{E}{E'}$, that

$$\frac{E}{E'} = \frac{1 + \dfrac{r + R}{R_x - R}}{1 + \dfrac{r' + R}{R_x' - R}}.$$

which resolved with regard to R_1 gives

$$R = \frac{R_x\,R\,(R_x + r') - R_x'\,E'\,(R_x + r)}{E\,(R_x' + r') - E'\,(R_x + r)}.$$

The use of this formula is legitimate only when the internal electromotive forces remain the same for the two observations.

P. H.

On the Currents of Emersion and of Movement of a Metal in a Liquid. By — Krouchkoll.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcvii., 1883, pp. 161–163.)

Two electrodes of the same metal plunged in a liquid give, when put in movement relatively to each other, in the liquid, a current the direction of which varies with the nature of the metal and of the liquid in contact. It is also known that, one of the electrodes

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[2] With the bridge if a is the side of the parallelogram contiguous to R_x and abutting with it to the extremity of the galvanometer-wire, b and c being the other corresponding sides of the bridge, $R_x = \frac{a\,b}{c}$; i being known for R_x, $\epsilon = \frac{a\,b\,i}{c}$, and calling s the resistance of the connections of the source of electricity to the bridge,

$$i = \frac{E}{R_x + a + (R_x + a)\,s\left(\frac{1}{R_x + a} + \frac{1}{b + c}\right)}$$

$$r = a + s\,(R_x + a\left(\frac{1}{R_x + a} + \frac{1}{b + c}\right).$$

being in the liquid, the immersion of the other produces a current at the moment of immersion; and the Author enunciates the following simple relation between these three kinds of currents: The current produced by the immersion is of contrary direction to that which produces the movement; the current of emersion is of the same direction as the current of movement.

P. H.

New Oxide-of-Copper Battery.

By F. DE LALANDE and G. CHAPERON.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcvii., 1883, pp. 164–166.)

This is a single liquid battery with solid depolarizer of oxide of copper, with caustic potash and zinc. It is sufficient to place the oxide of copper in contact with a plate or vessel of iron, constituting the positive pole of the element. Or the oxide may be agglomerated with cement of oxychloride of magnesium, into solid plates. Consumption is in proportion to work; the zinc and oxide of copper are not attacked by the alkaline solution. The electromotive force is about 1 volt. The internal resistance is low, about $\frac{1}{3}$ or $\frac{1}{4}$ ohm for polar surfaces of 1 square decimetre, separated 5 centimetres in a solution of 30 per cent. of caustic potash in water. These small cells will give as much as 2 ampères of current. Potash is preferable to soda, because of the tendency of the latter to decrepitate. The regeneration of this battery may be effected simply: the reduced copper easily absorbs oxygen on exposure to moist atmosphere.

P. H.

On the Measurement of Quantities of Current.

By G. LIPPMANN.

(La Lumière Électrique, vol. ix., 1883, p. 301.)

For the measurement of quantity of current in absolute units, the tangent galvanometer, or some special form of instrument, is generally employed. But to control these instruments, or to calibrate them, a more general method, dispensing with any particular form, is valuable; and the following the Author states to be susceptible of great accuracy.

The current to be measured is passed through a long copper wire stretched vertically. A small compass-needle is suspended at a distance a from this vertical wire; the axis of the wire and the centre of the needle are in the same magnetic meridian. Under the influence of a current of quantity i the needle is deflected to the angle α. If a is only a few centimetres, and the vertical wire

is more than a metre in length above and below the horizontal plane of the needle, the wire may be considered infinitely long. In this case,

$$(1) \qquad i = \tfrac{1}{2}\, a\, \mathrm{H} \tan \alpha.$$

H is the horizontal intensity of terrestrial magnetism = 0·193 at Paris. If $a = 103$ millimetres, the coefficient of tan α becomes equal to 1, and (2) $i = \tan \alpha$, where i is expressed in C. G. S. absolute units; and, to obtain the current in ampères, i must be multiplied by 10.

The preceding method is simple, and applicable in all cases where masses of iron or magnets do not interfere; where these are likely to introduce error the Author proposes the following method. The current to be measured is passed through a wire, on two points of which is placed a shunt-wire containing a galvanoscope and a Daniell element. The electromotive force of the Daniell element is opposed to the difference of potential between the points of application of the shunt circuit, and equilibrium [or no current in the shunt] is obtained. r being the resistance between the points of application in ohms,

$$i = \frac{1 \cdot 12}{r} \text{ ampères.}$$

P. H.

On a Universal Dead-beat Galvanometer.

By — DUCRETET.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcvii., 1883, pp. 254–256.)

This is a tangent galvanometer, the ring being arranged to be shifted along a graduated bar. The suppression of vibration is accomplished by complete immersion of the needle in a transparent liquid enclosed in a compass case. The Author claims that this immersion more nearly perfectly deadens oscillation than copper dampers or magnets, but leaves to the needle its full sensitiveness.

P. H.

On the Measurement of Differences of Potential by means of the Galvanometer. By L. THÉVENIN.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcvii., 1883, pp. 453–455.)

Amongst the practical consequences of the theorem of dynamic electricity, as presented previously[1] by the Author, is the experimental determination of the difference of potentials V and V′ at two points A and A′ of a network of conductors traversed by

[1] Ante, p. 381.

constant currents. The use of the electrometer furnishes a rigorous solution of the problem, and this solution is in every way the most satisfactory; but the setting up of the instrument is attended with difficulty, and the galvanometer is therefore generally employed. And if the branch containing the galvanometer is of very great resistance, the introduction of this resistance is considered not to sensibly alter the previous arrangement of circuits. The question arises as to what is meant by "very great" resistance, and the Author seeks to show that the accuracy must be only relative, and proposes a method that is no longer an approximation. In the following, R is the resistance of the network measured between the points A and A′, and r that of the galvanometer branch. It is shown that

$$V - V' = i\,(r + R),$$

i being current in r. The galvanometer, the resistance of which may be of any value, is arranged in derivation between the points A and A′, and the potentials of these points take the values V and V′. A standard resistance a is now introduced into the galvanometer branch, and i', the new quantity of derived current, is deduced from the new deflection of the needle. Then

$$V - V' = i\,(a + r + R).$$

Eliminating $r + R$ between these two relations,

$$V - V' = a\,\frac{i\,i'}{i - i'}.$$

If a is chosen, so that $i' = \frac{i}{2}$, the formula is simplified to

$$V - V' = a \times i.$$

This formula is rigorously exact, and is applicable however complicated the network.

From the preceding equations,

$$R = a\,\frac{i'}{i - i'} - g, \text{ or where } i' = \frac{i}{2},$$

$$R = a - g.^{2}$$

P. H.

Simple Consideration of Formulas relating to derivations on Telegraphic Circuits. By T. du Moncel.

(La Lumière Électrique, vol. ix., 1883, pp. 385–389.)

One of the causes intervening with some electricians in the course of their theoretic studies is the complication and multiplicity

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[2] g is evidently galvanometer and branch resistance (without a), though not so stated.—P. H.

of some of the laws and formulas. It is advisable to sacrifice some accuracy for the sake of simplification.

Amongst the complicated formulas are those concerning the dynamic reactions of currents and the derivations on telegraph lines, and more particularly in the latter the losses from leakage. Ohm's law shows by simple inspection that the point of a circuit where derivation is least injurious is by the battery; for if l represent the line, a the derivation, E the electromotive force of battery, and r its resistance, the quantity of current passing through l will be $\frac{E\,a}{r\,(a+l)+a\,l}$. Suppose, however, that the derivation occurs at any point of the line such that the part between the battery and the derivation is x' and the part beyond x, and that the circuit is further completed through earth, the total resistance T will be $x' + \frac{a\,x}{a+x}$ or $x' + \frac{(l-x')\,a}{(l-x')+a}$. If the resistance of the battery is comprised in the part x' of the circuit l the denominator in the expression for the current in this part becomes $x'\,(l-x') + la$, of which $x'\,(l-x')$ or $l\,x - x'^2$ admits of determining the maxima and minima conditions of I. That this value should be a maximum, the product must become zero, or $x' = l = 0$. In this case the derivation is supposed to occur near one of the poles of the battery. That I should be a minimum, x must be as great as possible. Denoting by n the maximum value of $l\,x' - x^2$, $x' = \frac{l}{2} \pm \sqrt{\frac{l^2}{4} - n}$. In order that this quantity may be positive or real, it is necessary that n be as large as possible, or equal to $\frac{l^2}{4}$ from which it is to be subtracted; hence $x' = \frac{l}{2}$, or the middle of the circuit is where the derivations would exert the most injurious influence. But as in telegraphic circuits the electromagnet has a resistance nearly equal to that of the line, it is, really, in the neighbourhood of the most distant point from the generator that the derivations are most injurious.

If the number of derivations be increased from one to d of equal resistance a, their total resistance will be $\frac{a}{d}$, and this resistance combined with that of the line, will give for I =

$$\frac{n\,E\,\frac{a}{d}}{n\,r\left(l+\frac{a}{d}\right)+l\,\frac{a}{d}},$$

the most favourable condition to instruments intercalated on the line. But if all the derivations are applied to the middle of the line, the effect is most prejudicial, and I' =

$$\frac{n\,E\,\frac{a}{d}}{\left(n\,r+\frac{l}{2}\right)\left(\frac{a}{d}+\frac{l}{2}\right)+\frac{a}{2\,d}\,l}$$

The Author then proceeds to examine several measurements of leakage through telegraph wire insulators, and deduces therefrom some constants which are embodied in the following further consideration. For the most simple case, T is $= \frac{l\,a}{a+d\,l'}$, which is susceptible of a maximum. For, for a length of line l', the ratio of the total resistances becomes $\frac{l}{l'} \times \frac{(a+d\,l')}{(a+d\,l)}$, or, representing by p the distance between the points of derivation (corresponding in practice to the distance between the telegraph poles)

$$\frac{l}{l'} \times \frac{p\,a+l'^2}{p\,a+l^2},$$

whence the Author deduces $l = \sqrt{p\,a}$, and, as a condition of maximum, $T = \frac{l\,a\,p}{l^2+a\,p}$ or $\frac{a\,p}{l+\frac{a\,p}{l}}$.

But in the case where the derivations occur in the middle of the circuit, the total resistance

$$T' = \frac{l\,a}{2\,a+d\,l} + \frac{l}{2} = \frac{l\,a\,p}{l^2+2\,a\,p} + \frac{l}{2},$$

which is no longer susceptible of a maximum.

If from the equations giving the values of I and I′ are deduced the numbers of elements of battery that it is necessary to employ to obtain these quantities, the following expression is arrived at—

$$1^{\circ} - n = \frac{l\,I\,a}{a\,E - r\,I\,(a+l\,d)}\quad 2^{\circ} - n' = \frac{(4\,a+l\,d)\,I'}{4\,E\,a - 2\,I'\,r\,(2\,a+l\,d)}.$$

This shows it is not always possible to obtain a given quantity on a telegraphic circuit even by indefinitely increasing battery power. Indeed, the limit values of n (in the case where all the values l, I, a, d are known) are attained when $1^{\circ}: a\,E = r\,I\,(a+l\,d)$; $2^{\circ}\ 4\,a\,E = 2\,I'\,r\,(2a+l\,d)$; that is to say, supposing the telegraph posts are 75 metres apart, $1^{\circ}\ l = \sqrt{\frac{a\,(E-r\,I)}{r\,I}} \times 75$ and $2^{\circ}\ l' = \sqrt{\frac{2\,a\,(E-r\,I')}{r\,I'}} \times 75$, whence it may be concluded that the length of a telegraph line on which a given quantity is to be obtained is somewhat limited.

The minimum value of a corresponding to a given quantity with an infinite number of battery elements is $a = \frac{3\,\mathrm{R\,I}\,l\,d}{4\,(\mathrm{E} - \mathrm{R\,I})}$.

It is better to designate by x and x' the resistances at the two extremities of the line not subject to derivation, without evaluating them precisely until the complete discussion of the formula. The expression, giving the value of I in the case even of derivations taken on the battery poles, then, is,

$$\mathrm{I}' = \frac{n\,\mathrm{E}\,a}{(n\,\mathrm{R}+x)\,(a + (l - x + x')\,d) + a\,(l - x + x')}.$$

In this manner there may be given to x and x' different values permitting of discussing different cases. Thus if x' represents the resistance of an electromagnet, and if x is supposed variable, the worst conditions of the value of I′ will be furnished by the maximum of the denominator of the formula, which maximum corresponds to

$$x = \frac{l + x' - n\,\mathrm{R}}{2} = \frac{l}{2} + \frac{x' - n\,\mathrm{R}}{2},$$

that is, to half the line resistance increased by half the difference of the resistances of the electromagnet and of the battery.

P. H.

On Funicular Curves. By Dr. H. Zimmermann.

(Centralblatt der Bauverwaltung, 1883, p. 231.)

A simple graphical method is given for drawing the aklinoid, *i.e.*, the funicular curve for the weight of a uniform substance (stone) confined within a horizontal line (roadway) and the curve itself (arch) by means of two corresponding pencils of rays. The pole of the first is vertically opposite the apex, and the tangents of the angles of the rays with the vertical are 0·1, 0·2, 0·3, &c.; the pole of the second is horizontally opposite the apex, and the tangents of the angles corresponding with the horizontal are $-1 + \cos 0{\cdot}1$; $-1 + \cos 0{\cdot}2$, &c., according to

$$\cos\phi = 1 + \frac{\phi^2}{1.2} + \frac{\phi^4}{1.2.3.4} + \frac{\phi^6}{1.2.3..6} + \&c.$$

This construction is based upon the equation of the aklinoid:

$$y = y_0 \cos\frac{x}{\sqrt{h}} = y_0 \cos\frac{x}{\sqrt{\mathrm{R}\,y_0}},$$ [1]

where y_0 is the depth of the substance at the apex, h the horizontal

[1] Rankine, "Civil Engineering," pp. 201 and 418.

thrust expressed in units of its volume, and R the radius of curvature at the apex.

It is then only necessary to draw through the first pencil of rays a horizontal line at the distance $\sqrt{R\,y_0} = \sqrt{h}$ from its pole, and through the second a vertical line at the distance y_0 from its pole. The corresponding points of intersection of the lines with the rays projected vertically and horizontally give the points of the curve.

In practice generally, f, the rise, and $2\,l$, the space, are given, besides y_0, but not R or h; but from the diagram can be seen directly how $\sqrt{R\,y_0}$ is found with f and $2\,l$. The two pencils of rays once drawn can be used for the drawing of all kinds of aklinoids, and also of the common catenary, whose equation is

$$y = h \frac{\cos x}{h}.$$

M. A. E.

Norton's Automatic Can-Making Machinery.

(American Machinist, vol. vi., 1883, p. 1.)

The machinery described is constructed by Norton Brothers, Chicago, and is used by the Pacific Can Company and others for the manufacture of tin cans such as are used in hermetically sealing fruits, vegetables, fish, meat and all goods requiring air-tight package.

The series of machines is completely automatic. The tin is fed in the sheet into a machine which cuts it into bodies, thence into a second machine which discharges the body seamed up ready for soldering; next the side seams are soldered; thence the bodies pass into an automatic machine, where they meet the tops and bottoms, and they emerge ready for the end soldering, which is done in another machine.

The range of the machines is from 1-lb. salmon-cans to 1-gallon fruit-cans. The uniform size of the cans permits of close-fitting ends, which effect a considerable saving in solder over those made by hand, while the labour saved is as six to one.

The soldering of the side is done by means of an endless carrier, each link of which carries a can-body forward, first through a bath of flux, then up an incline which drains it out, thence through a bath of molten solder, the can-body being carried by means of the links on a track shaped so that only the circular portion containing the grooved seam is immersed in the solder. As the cans leave the bath they are carried up a sharp incline, which causes the molten solder to flow out, and the can then passes through a funnel which rounds it up and supports it, while asbestos wipers wipe off the surplus solder. The cans are then carried over blasts of cold air, which cool and set the solder. The

capacity of this machine is fifty side seams per minute, large or small.

The ending-machine consists of a revolving turret, having a series of half moulds on its periphery. As the turret revolves the moulds take up one body after another, a curved guard retaining them until they reach the bedplate of the machine, where they register accurately with a corresponding half mould which is mounted on a reciprocating crosshead and driven by means of cams from the main shaft of the machine. The heads are fed singly through hoppers to the mould, where they are met by pistons and forced into the mould and on to the can-body with the greatest accuracy. The reciprocating half mould and the pistons then withdraw, the turret revolves and the cans are expelled and are delivered to the soldering machine. The latter machine is on the same principle as the side-soldering machine; the cans are heated as they roll along, and pass through baths of flux and solder, and are afterwards cooled.

The capacity of the plant is about three thousand cans per hour.

W. P.

Forest-Conservancy in British Guiana.

By M. McTurk, G. M. Pearce, and the Hon. W. Russell.

(Journal of the Royal Agricultural and Commercial Society of British Guiana, Dec. 1882, p. 173.)

These Papers refer to the forests of British Guiana; they give information as to the trees to be found in the district, the system of cutting, the inadequacy of the legal restrictions on cutting, and the necessity for new regulations. There are large tracts of which the ownership even is doubtful. The country consists of a belt of forest from 100 to 200 miles broad, containing a variety of durable and ornamental woods, probably unsurpassed by any other country. Mr. McTurk gives a description of the principal trees, many of which, greenheart for instance, can be had in logs from 18 to 24 inches square and 70 feet long. Red and white mora are found from 180 to 200 feet high, and may be squared to 24 inches. Waihama averages about 90 feet in height, and may be squared to 20 to 28 inches. It is probably superior to greenheart for all purposes for which that timber is used, and deserves to be placed among the first-class woods at Lloyd's for ship-building. Wallaba (*Eperna falcata, Aubl.*) is suitable for house-frames, vat-staves, poling-staves, and shingles; its average height is 80 feet, and it will square to 20 inches. Determa is a light strong wood for planking boats, for building railway-carriages and other purposes; its height is about 100 feet, and it can be had to square up to 30 inches; it is also used for masts and spars. Kabukalli is good for boat-building; its average height is 120 feet, and it will square to

30 inches. Tataboo grows to a height of 80 feet, may be squared to 22 inches, is very hard, and suitable for mill-beds, boat-building, house-framing, &c. Pakoorie is very durable, suitable for house-framing, averages 80 feet high, and can be squared to 36 inches. Kurana, or red cedar (*Icica altissima, Aubl.*), grows to a large size, and is plentiful in some localities. It is a most valuable wood, averages 100 feet in height, and is sometimes 38 or 40 inches in diameter. Kooroobooreلli, or purple-heart (*Copaifera ubiflora* and *bracteata, Benth.*) averages 120 feet, and is often found 200 feet high, and can be squared to 30 inches. It is very hard, close-grained, durable and tough, and is capable of resisting great strain.

In addition to the above Mr. McTurk describes nearly fifty other kinds of timber, many of them valuable.

Practically no restrictions as to size, time of cutting, or kind of trees to be cut, are placed on the wood-cutters. The aboriginal Indians are allowed to cut timber on any part of the unoccupied Crown lands. The first step to be taken towards conservancy is to settle the rights of ownership and to define owners' boundaries. Licences for wood-cutting should be granted; no trees should be cut merely for the seed and bark. The sizes below which the various kinds of trees may not be cut should be defined, according to a table in the Paper. The rights of the Indians should be looked into, as these rights are improperly exercised by half-breeds. Improved means of water-communication are required. Officers should be appointed to reside in the districts and enforce the regulations. Restrictions should be put upon cutting timber for path making; and some attempt should be made to prevent the destruction of other trees, caused by felling, and the indiscriminate cutting down of young wood for rollers. Charcoal burning, which entirely destroys the forests, should be restricted by the imposition of a heavy export duty.

W. H. T.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1882–83.—Part IV.

END OF VOL. LXXIV.

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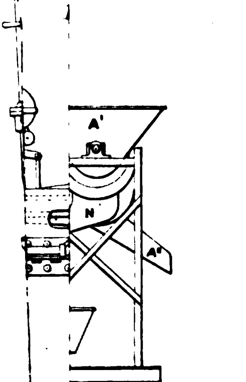
STAMFORD STREET AND CHARING CROSS.



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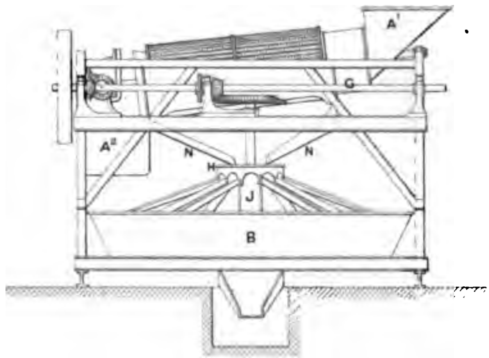

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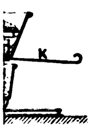

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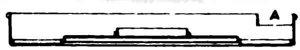

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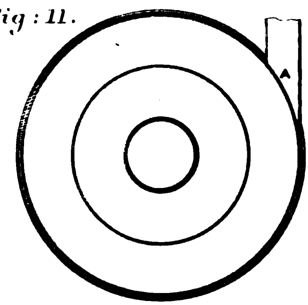

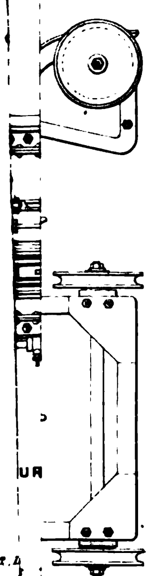

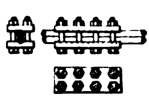

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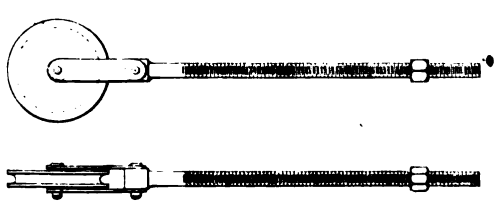
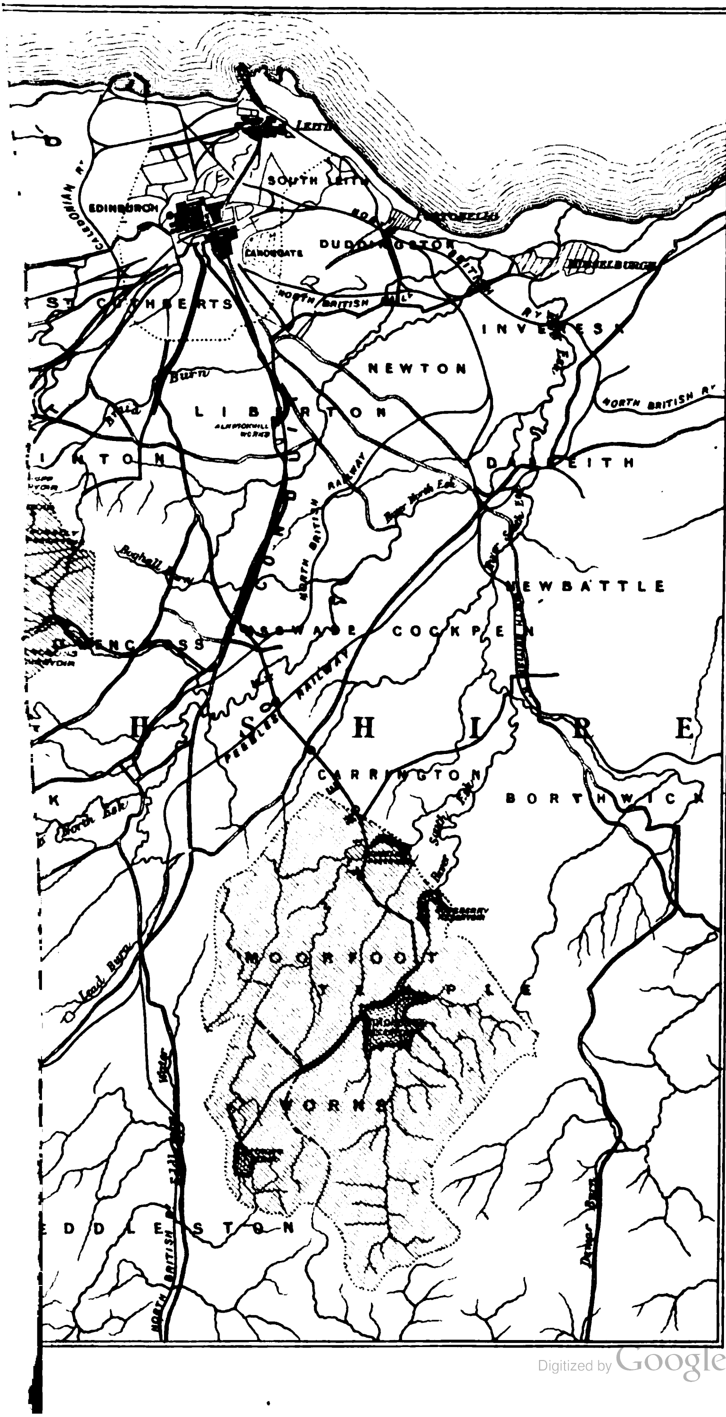


.5, 6, 12. D

STRAINING SCREW AND STANDING WIRE ROPE CLIPS.


Leith
SOUTH LEITH
EDINBURGH
CALEDONIAN RY
CANONGATE
PORTOBELLO
MUSSELBURGH
NORTH BRITISH RAILY
NEWTON
NORTH BRITISH RY
Burn
Braid
LIBERTON
NORTH BRITISH RAILWAY
NEWBATTLE
COCKPEN
PEEBLES RAILWAY
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CARRINGTON
BORTHWICK
North Esk
South Esk
MOORFOOT
WORKS
Lead Burn

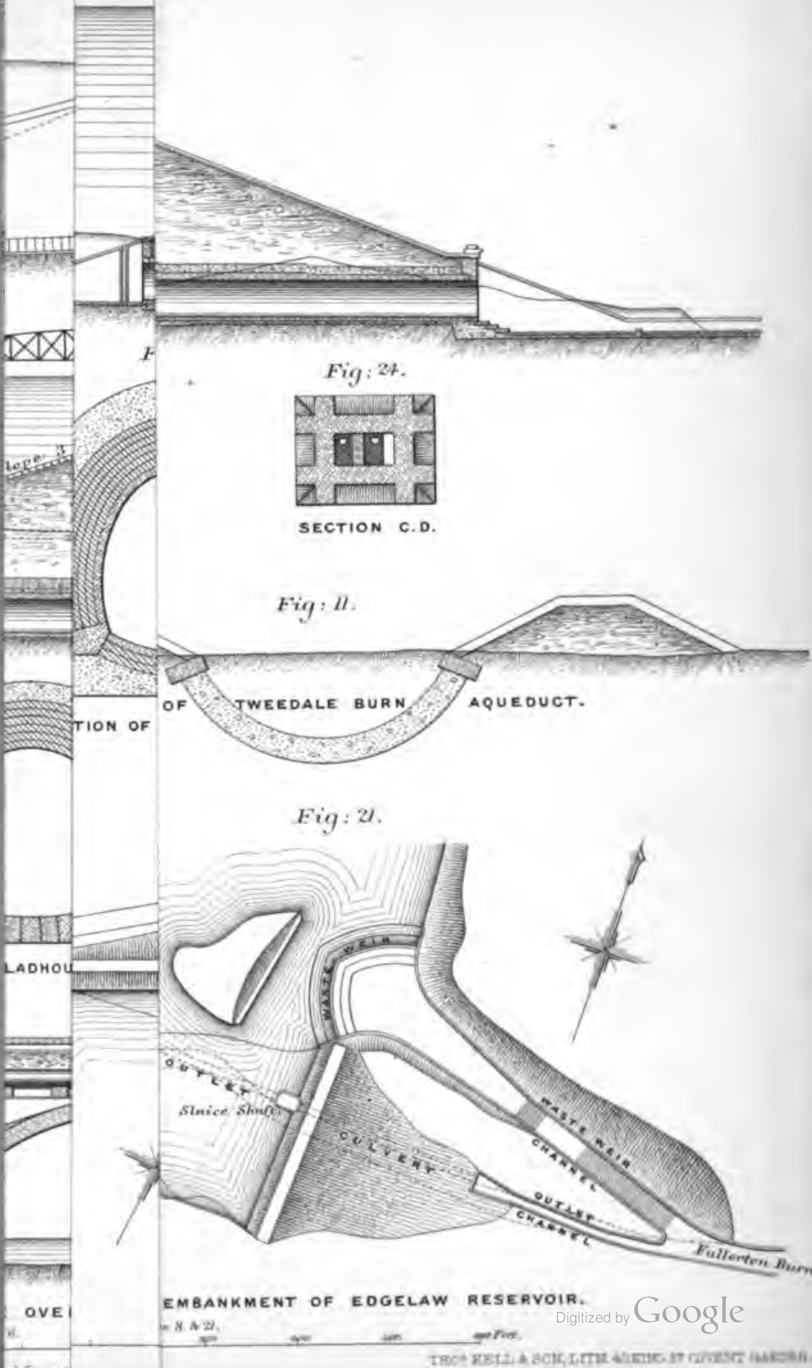
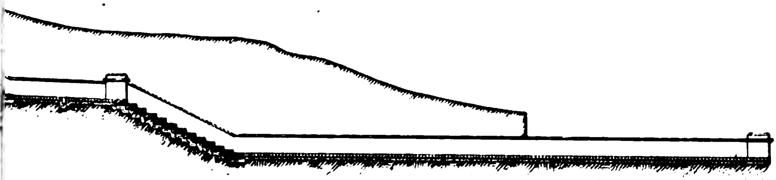


Fig: 24.
SECTION C.D.
Fig: 11.
TION OF
OF TWEEDALE BURN AQUEDUCT.
Fig: 21.
LADHOU
WASTE WEIR
OUTLET
Sluice Shaft
CULVERT
WASTE WEIR
CHANNEL
OUTLET
CHANNEL
Fullerton Burn
OVE
EMBANKMENT OF EDGELAW RESERVOIR.



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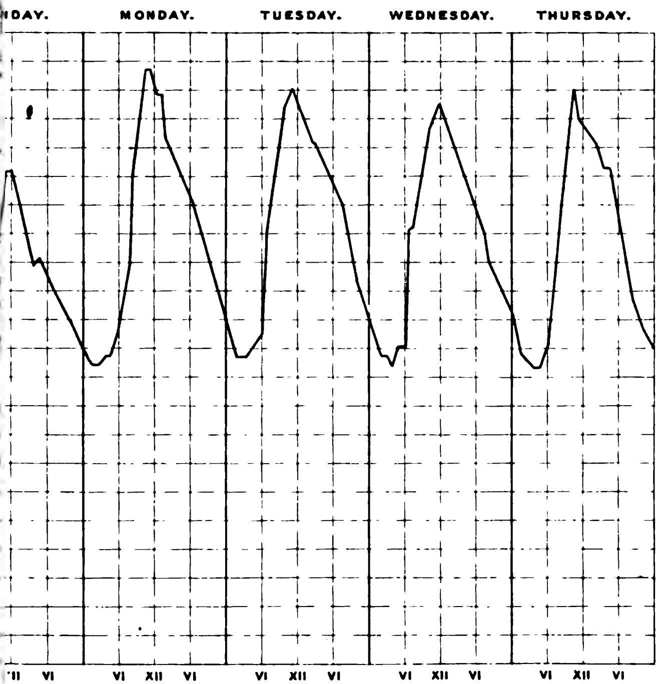
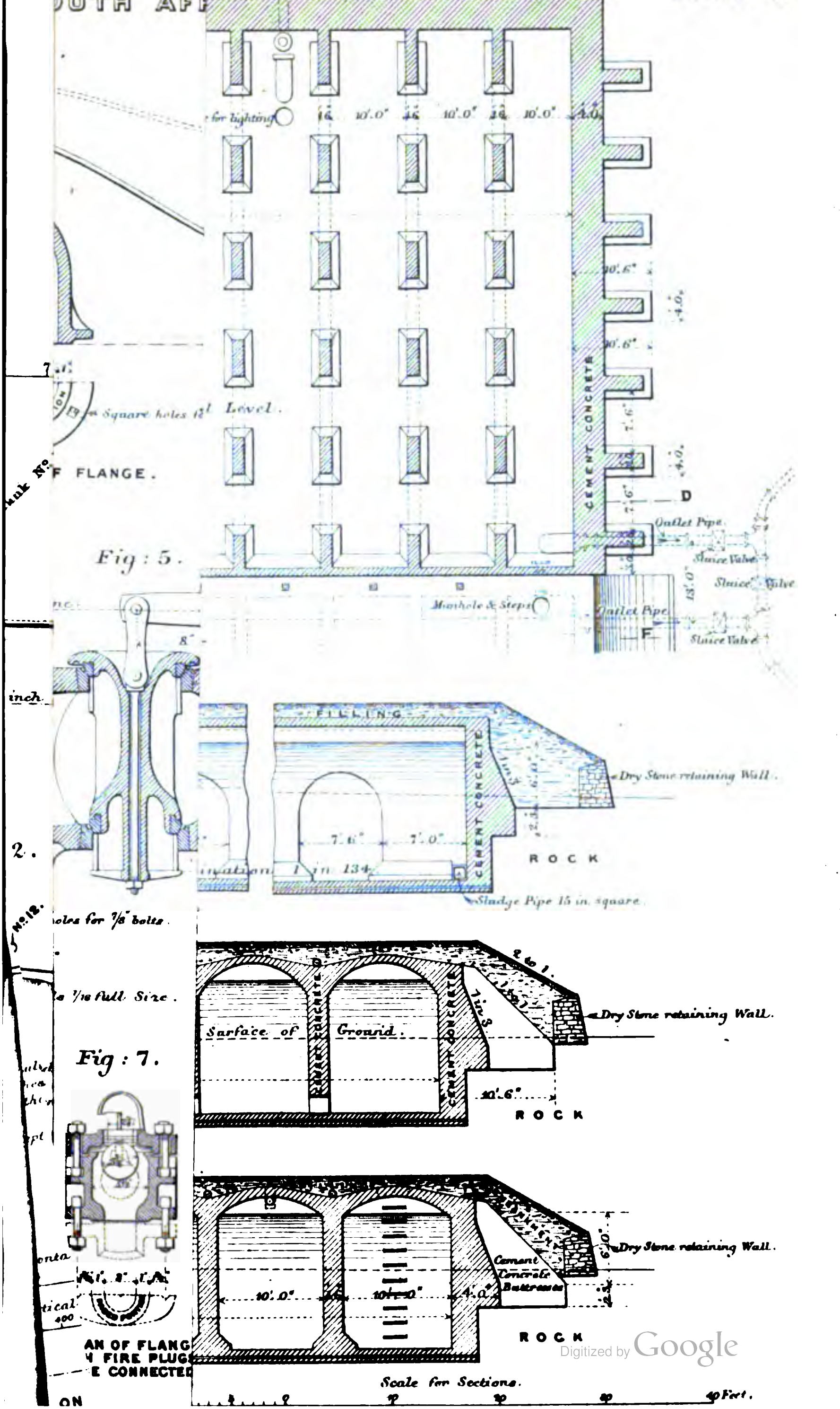


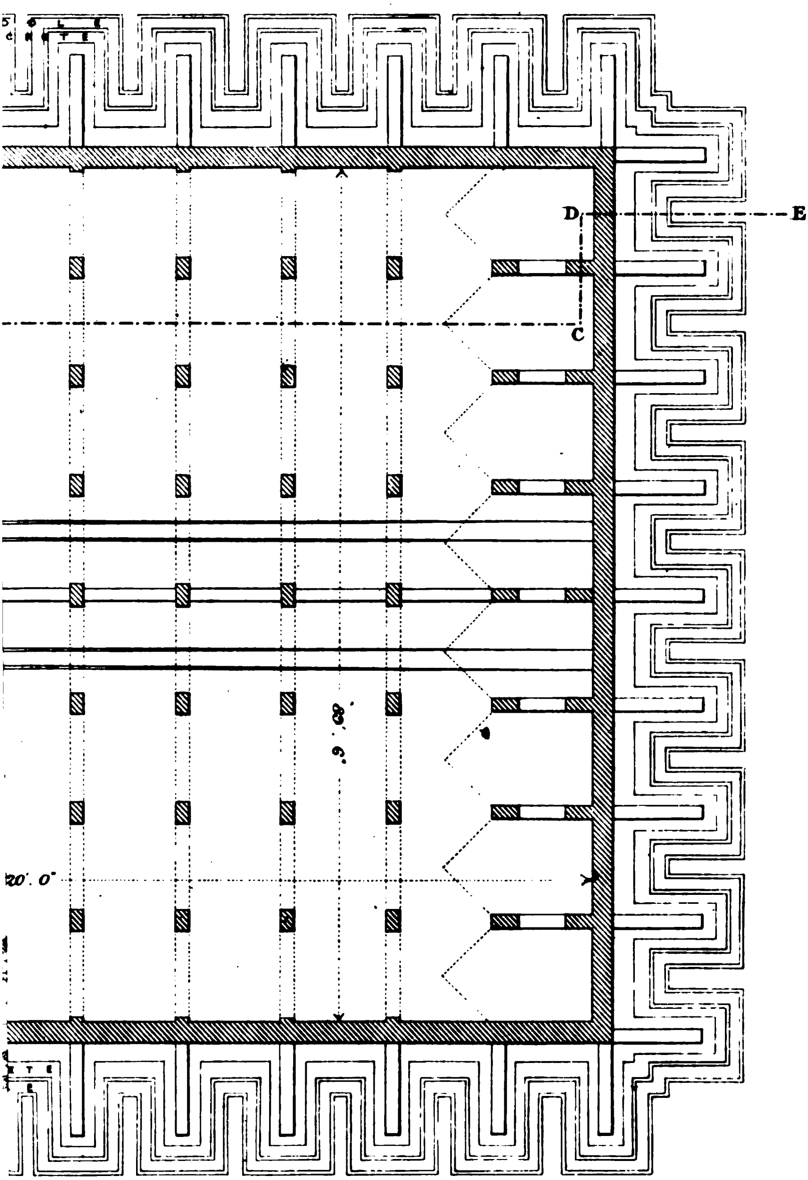
WING RATE OF CONSUMPTION OF WATER.

THOS KELL & SON. LITH 40 KING ST COVENT GARDEN

PLATE 5.


OUTH AF
for lighting
1'6"
10'.0"
10'.6"
4'.0"
7'.6"
D
Outlet Pipe
Sluice Valve
13'.0"
Manhole & Steps
F
Square holes
Level
F FLANGE.
Fig : 5.
inch
2.
FILLING
CEMENT CONCRETE
Dry Stone retaining Wall.
7'.6"
7'.0"
ROCK
1 in 134
Sludge Pipe 15 in. square
holes for 7/8" bolts.
1/10 full Size.
Fig : 7.
2 to 1.
Surface of Ground.
1 in 8
10'.6"
10'.0"
4'.0"
6'.0"
Cement Concrete Buttresses
AN OF FLANG
FIRE PLUG
E CONNECTED
ON
Scale for Sections.
40 Feet.

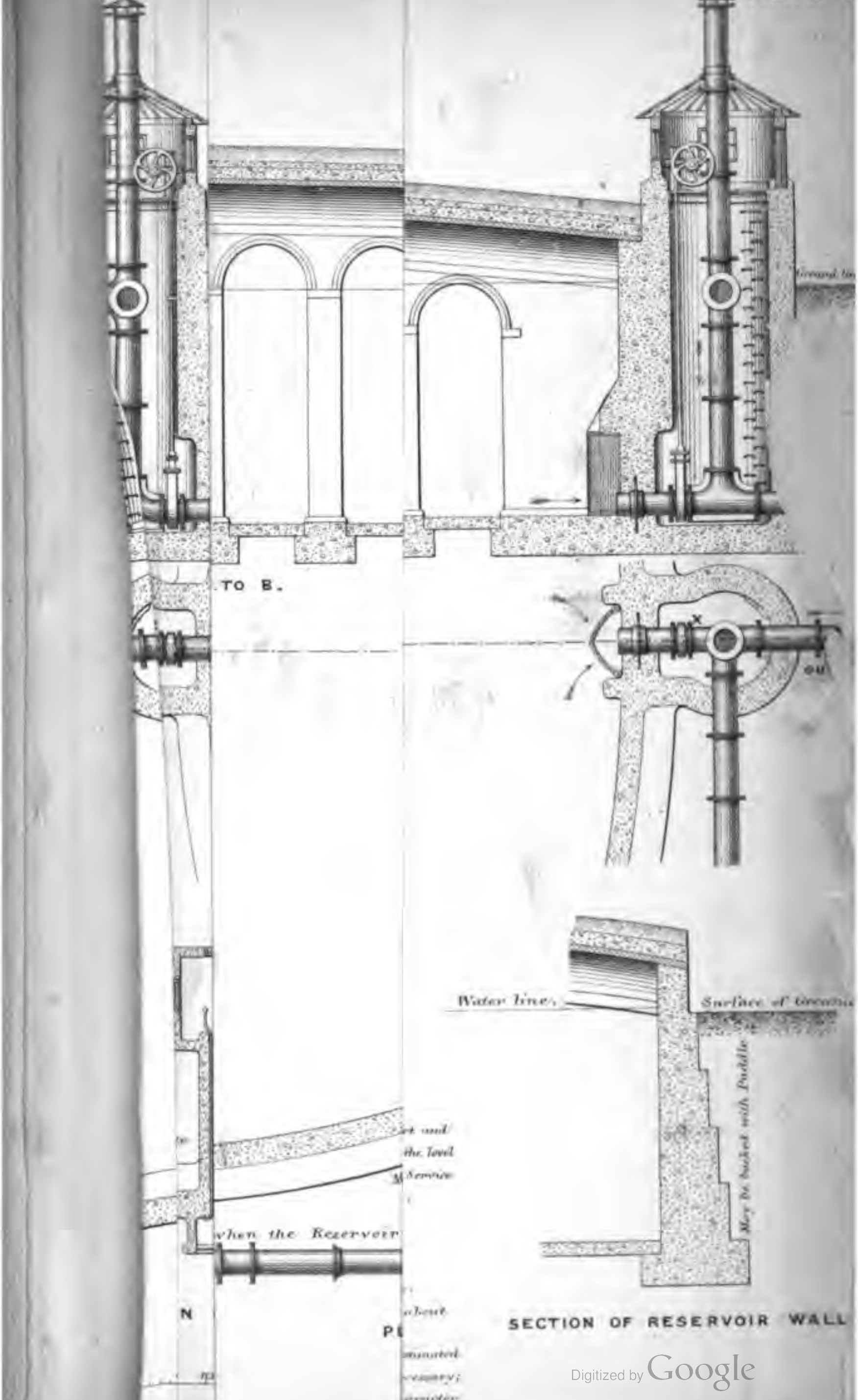
g . 3.



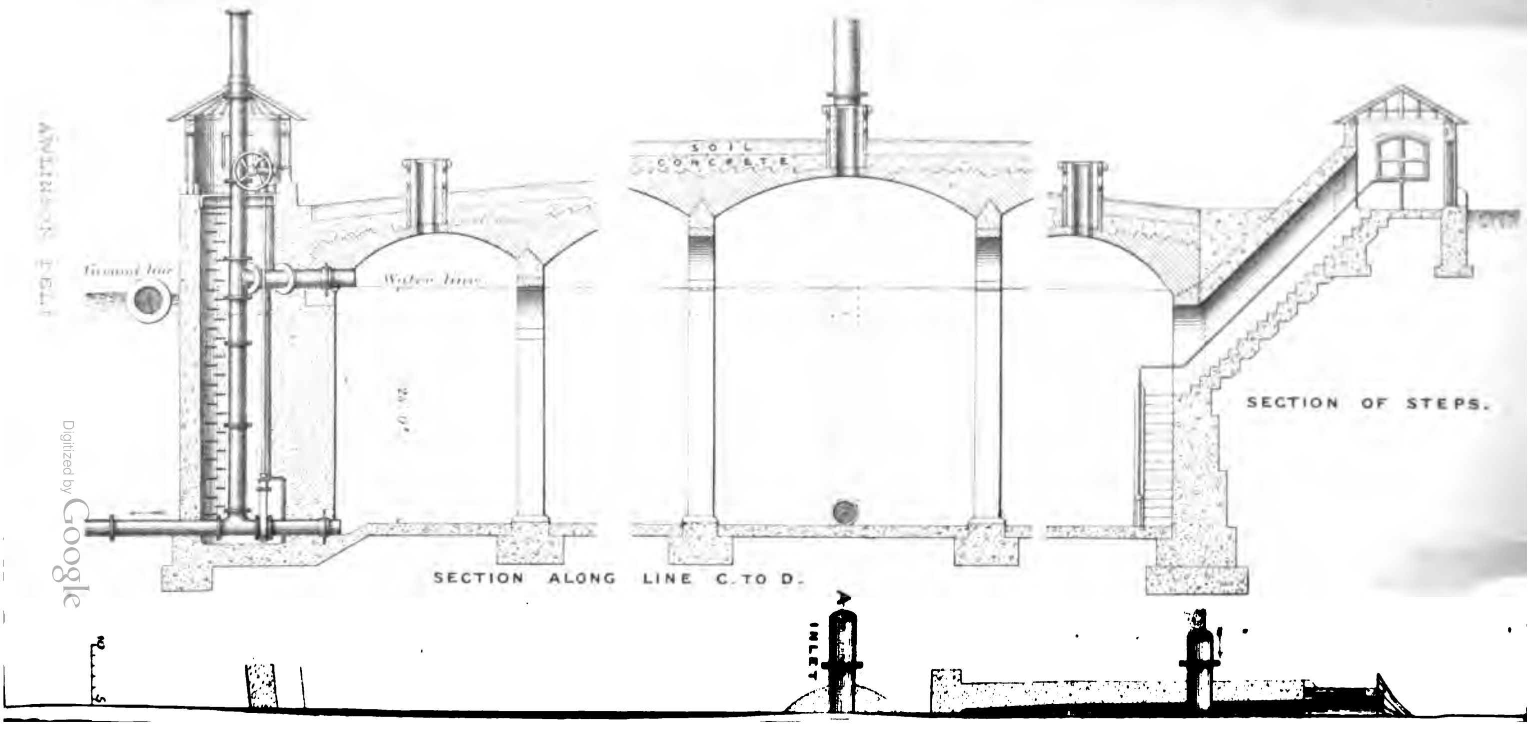
, CAPACITY 1,000,000 GALLONS.

THOS KELL & SON. LITH. 40 KING ST COVENT GARDEN.

PLATE 7



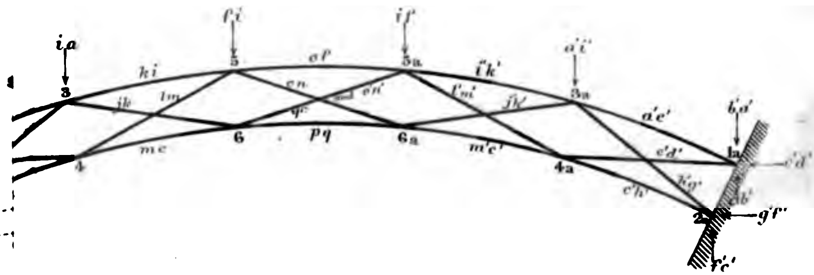
SECTION OF RESERVOIR WALL



SECTION ALONG LINE C. TO D.

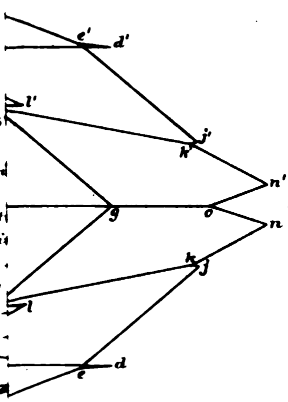
Fig: 11.

FRAME OF BRACED ARCH.



NOTE: *The horizontal and vertical reactions are assumed to be divided equally at* **1** *and* **2**, *and* **1a** *and* **2a** *respectively.—*

IAGRAM.

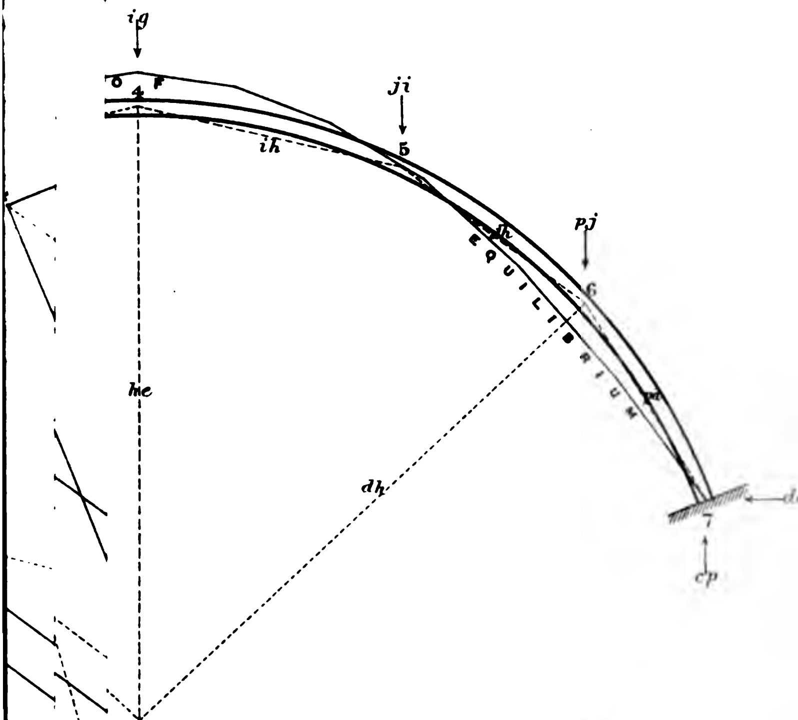


1.	$a - b - c - d = e = a$	
2.	$c - f - g = h = c$	
3.	$i - a - e - j = k = i$	*ej equal and parallel to hg*
4.	$c - h - l = m = c$	*hl* . . . . *ed*
5.	$f - i - k - n = o = f$	*kn* . . . . *ml*
6.	$c - m - p = q = c$	*mp* . . . . *kj*
1a.	$d' - c' - b' - a' = e' = d'$	
2a.	$g - f - c' = h' = g$	
3a.	$j' - e' - a' - i' = k' = j'$	*j'e'* . . . . *gh'*
4a.	$l' - h' - c' = m' = l'$	*l'h'* . . . . *d'e'*
5a.	$n' - k' - i' - f - o = n'$	*n'k'* . . . . *l'm'*
6a.	$p' - m' - c' = q' = p'$	*p'm'* . . . . *j'k'*

closing on n — cq.

Fig : 10.

UREBRACED ARCHED RIB.



RESSES IN A CIRCULAR ARCHED RIB THROUGHOUT WHICH THE
LD IS NOT CONTAINED.

m for the given Loading of about equal length to
ints on the centre line of the latter where it is at its
Curve suppose Members to be introduced, connecting
point at centre of Arch. —
wo Curves transverse strains are evidently nil. —
th is at its maximum distance from the Curve, the
the same as would be produced in a Girder of the
ions of the Rib between the intersections, with a load
ual to the stress on the supposed introduced member. —
posed member may be obtained by the graphic

c = d = b
b – d = e = f
f – e = g closing on g.
g – e = h = i
i – h = j closing on j.
p – j = h = d closing on d.
c – p – d

Fig. 1.

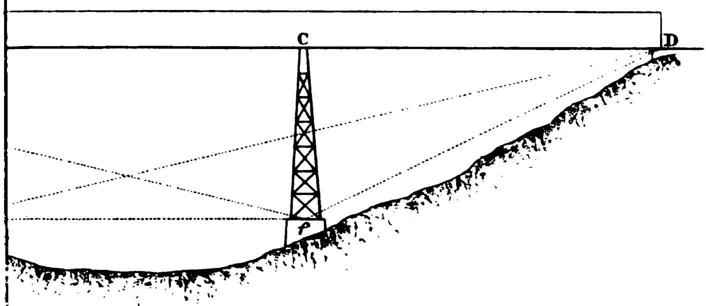


Fig. 2.

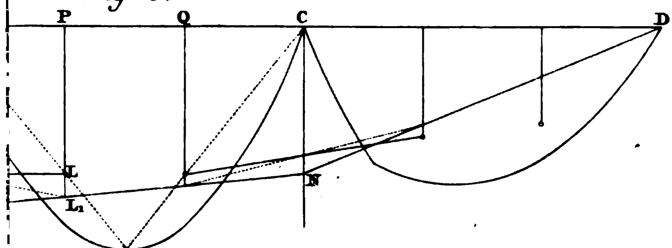
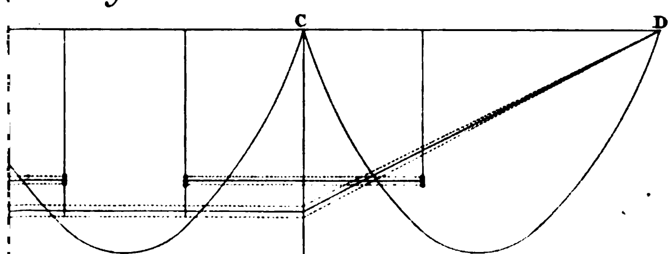


Fig. 3.



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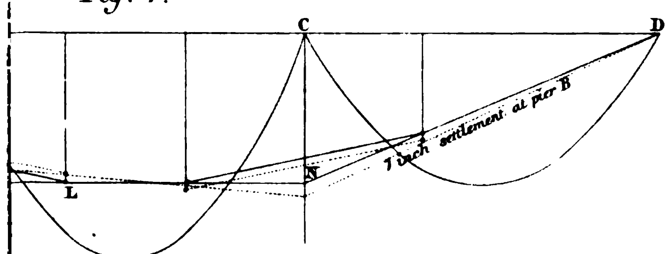

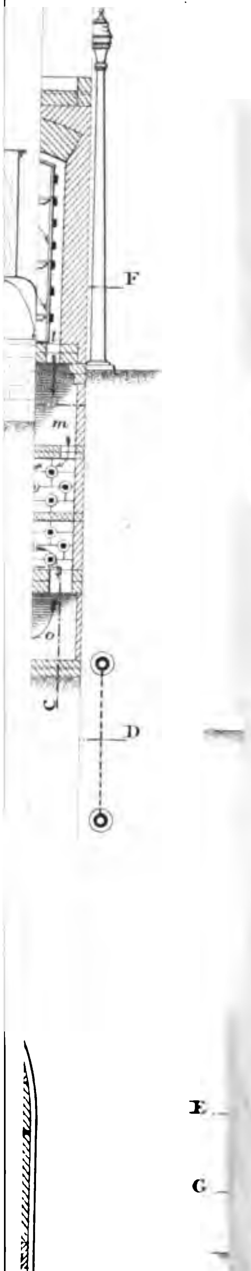

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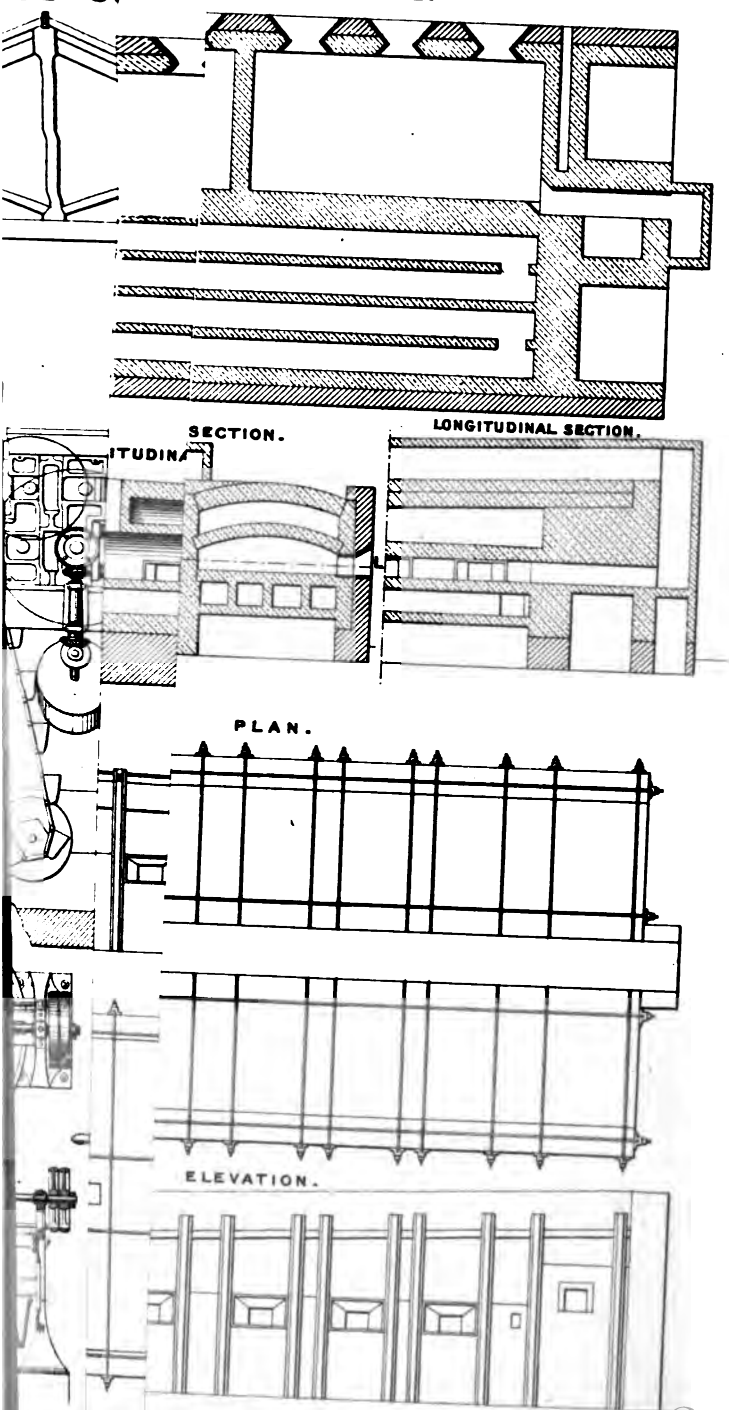
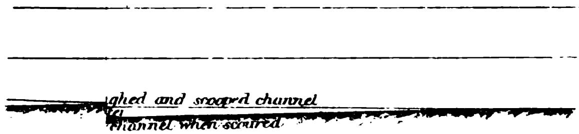
V.Sess

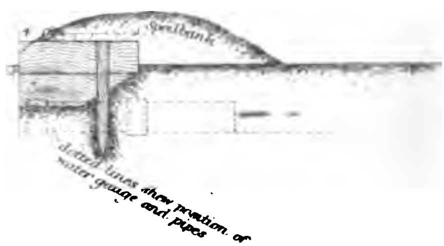


ASHING DE FURNACE.

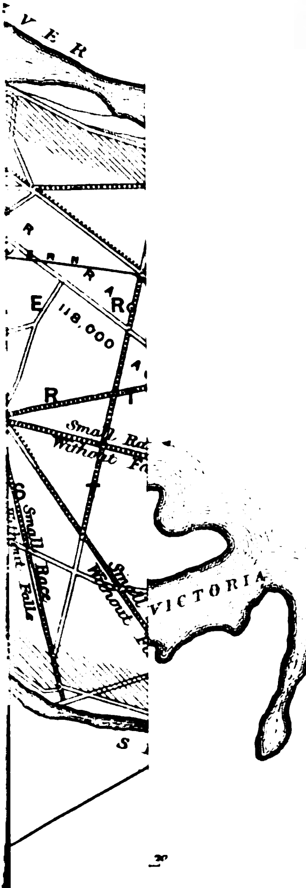
2-83 Pa

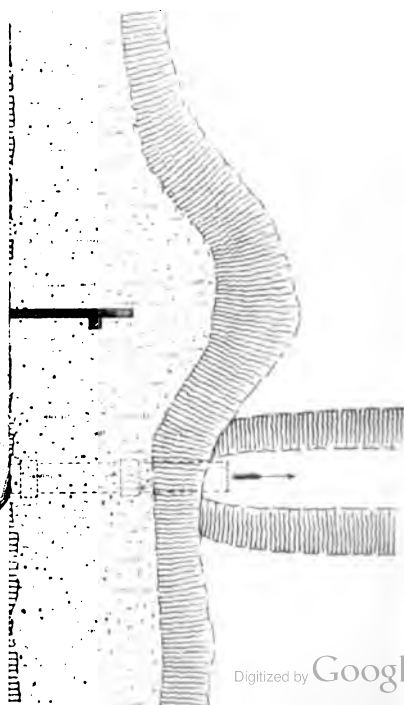
THOS KELL & SON LITH 40 KING ST COVENT GARDEN

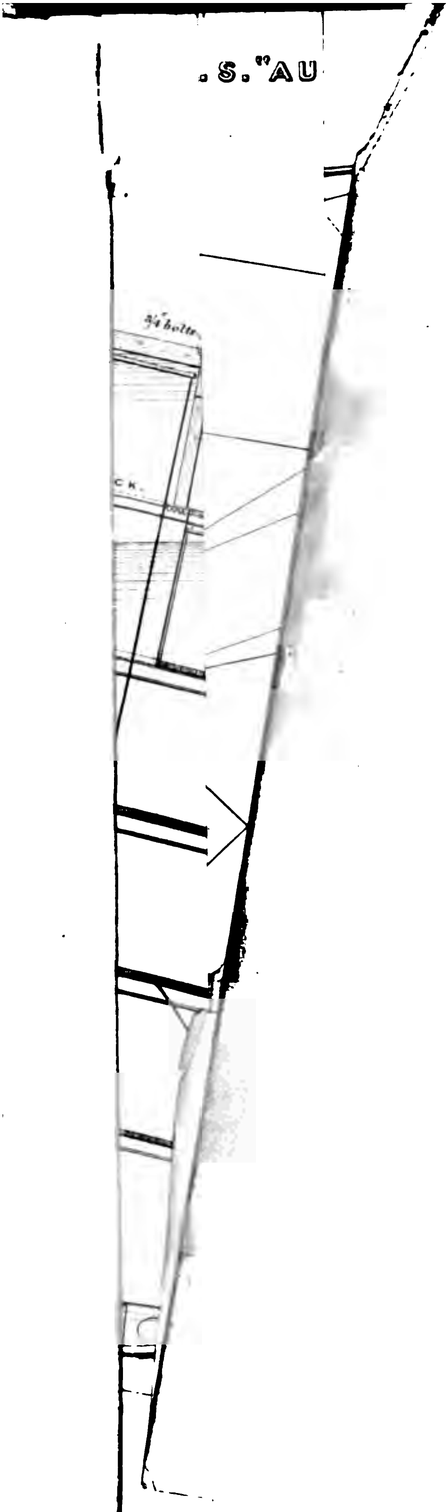

ghed and scoured channel
channel when scoured


Spoilbank
dotted lines show position of water gauge and pipes

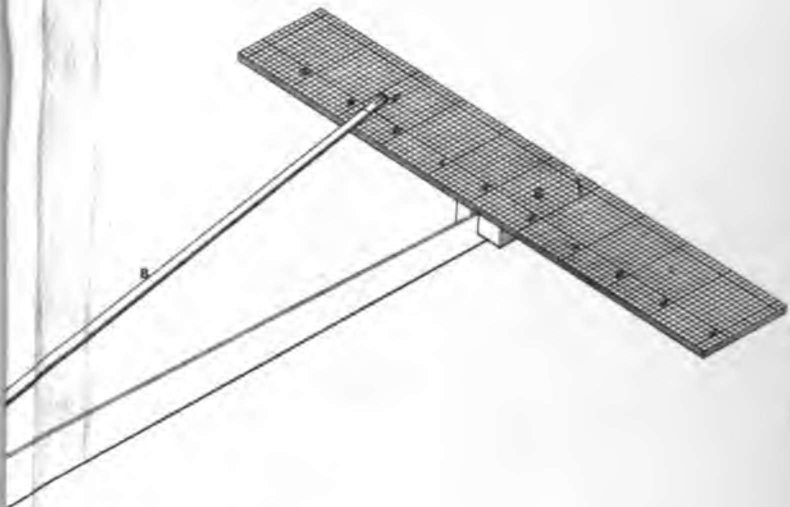
R.


V E R
E
R
118,000
R
Small Rock
Without Falls
Small Rock
Without Falls
S
VICTORIA

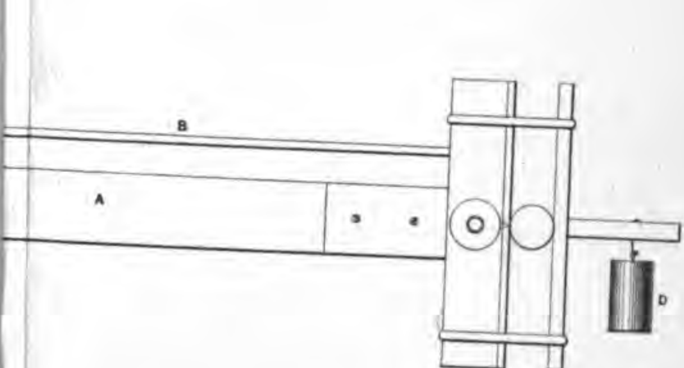




XIV. Session

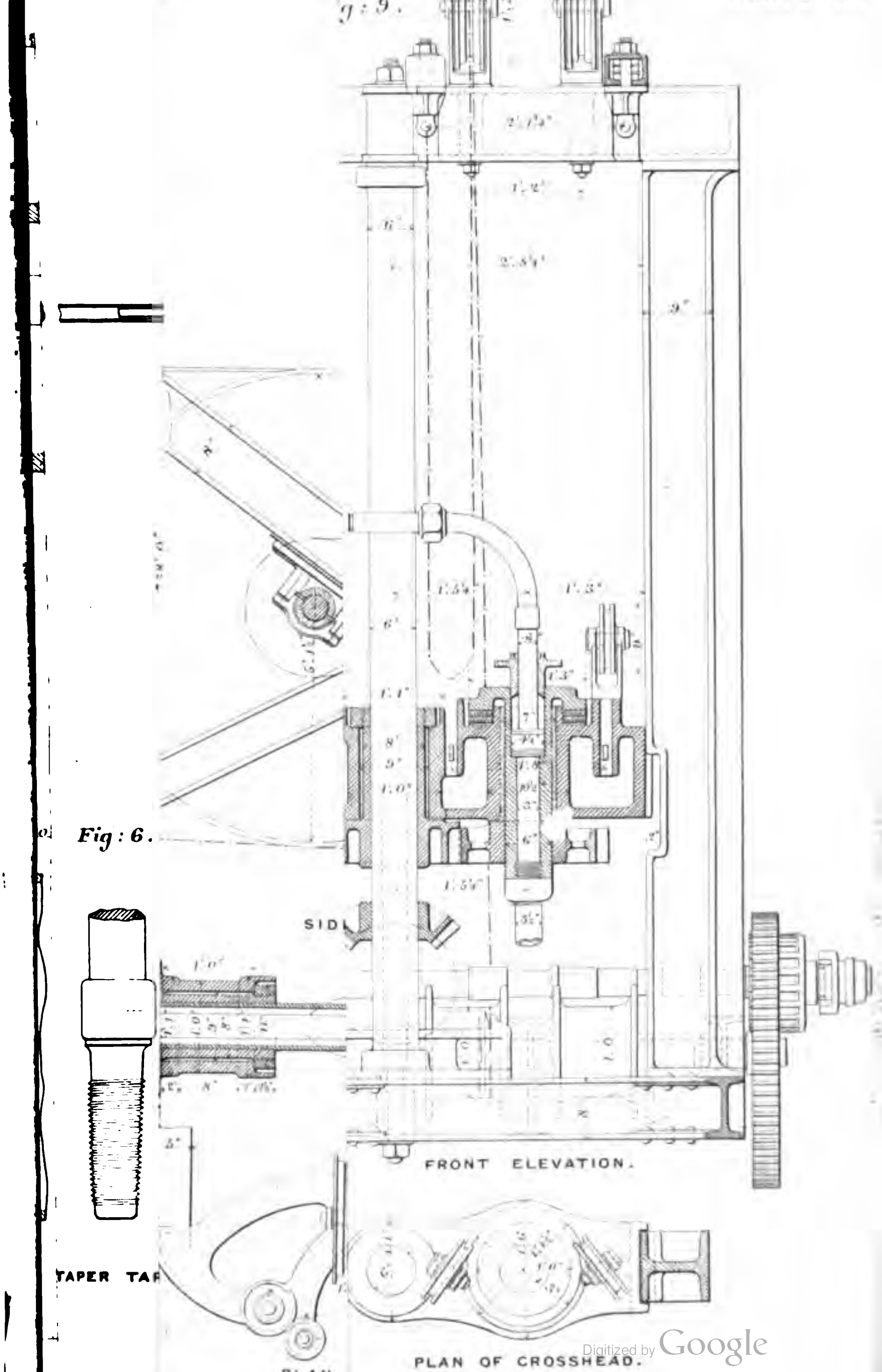


Figs: 20.



BOR

PLATE 16.



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